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Clamping a 100 kw tube into its socket at the WLW 500 kw radio broadcasting station in Cincinnati, Ohio. (For a description of this station see I.R.E. Proc., v. 22, 1934, p. 1151–80.)
Photo courtesy Institute of Radio Engineers

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## Power Generation



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Act Now!

# Mapping of Fields

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**Field theory, as contradistinct to circuit theory, is shown in this article to become increasingly important in a large number of engineering problems. In addition to the more familiar electric and magnetic fields there are temperature, mechanical stress, hydraulic flow, and other field concepts all reducible to the same mathematical basis. An outline of some of the methods employed in dealing with stationary fields is presented in this paper, conjugate functional methods and conformal representation being considered in detail, preceded by a brief consideration of experimental reproduction, graphical mapping, and mathematical solutions of field problems. This is the twelfth of a series of special articles developed under the sponsorship of the A.I.E.E. committee on education.**

In engineering practice it is generally required to find solutions to problems in a simple and convenient form easily interpretable and easy to visualize. This accounts for the almost exclusive use of the "circuit concept" as contradistinct to the "field concept." Although all phenomena occur in space and time, and as such are field phenomena, it is possible to approximate them by time relations only, summarizing the actual physical constants by means of parameters, preferably of constant value. This elimination of the space concept has been responsible for much of the spectacular development of engineering science. However, as time goes on it becomes increasingly evident that the small group of scientific engineers has repeatedly had reason to reëxamine the basis of the circuit concept and to refine methods of computation by basic work in field theory.

This paper shall, in brief, outline some of the methods employed in dealing with stationary field problems, and is restricted to a survey rather than an exposition of the subject. The rather extensive bibliography can give only meager indication of all the work done in this branch of mathematical physics, and, therefore, only fundamental contributions have been included, selected in some cases because of valuable reference lists contained in the text.

## Fundamental Properties of Fields

A *field* is defined as a region of space where in addition to the qualities of space proper there is a physical quantity assignable to each point as a continuous function of the coördinates. So, for example, a temperature field is defined as the relation between temperature $T$ at any point within a certain region of space and its coördinates. Temperature is a *scalar quality* in so far as only numerical value and unit are needed to specify it completely. As another example, the electrostatic field is explored and defined by the field strength $\boldsymbol{E}$, which is a *vector*, needing for its complete determination in addition to numerical value and unit also directional specifications. It is, therefore, customary to distinguish between scalar fields and vector fields.[1]

There are certain types of fields which are of particular importance in theoretical physics because of their organized structure. Obviously, only univalued relations can have physical significance if causality is adhered to for macroscopic phenomena.

Consider, then, a vector field, defined in general by the field vector $\boldsymbol{A}$. Mathematically, differentiations and integrations are most important operations and if these lead to simple forms it may be concluded that the field structure is highly organized. An example is the gravitational force field $\boldsymbol{F}$. Integration along a path with end points $P_1$ and $P_2$ of the form $\int_{P_1}^{P_2} \boldsymbol{F}.d\boldsymbol{s}$ represents work done or energy expended by the field along this path. Obviously, the simplest force field must be one where this integral does not depend upon the path chosen but only upon the 2 end points $P_1$ and $P_2$, as is the case in the gravitational field. If integration follows such regularity some inherent restriction may be suspected on the rate of change in space of the vector, or in other words, of its differential quotients, and, indeed, it is possible to derive for the gravitational field the relation curl $\boldsymbol{F} = 0$ as an equivalent statement.[1] (In cartesian coördinates the vector notation curl $\boldsymbol{F} = 0$ is equivalent to the 3 scalar equations

$$\frac{\partial F_z}{\partial y} - \frac{\partial F_y}{\partial z} = 0, \ \frac{\partial F_x}{\partial z} - \frac{\partial F_z}{\partial x} = 0, \ \frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y} = 0.)$$

But if the vector has no circuitation it can be shown that there is a scalar function correlated with it such that $\boldsymbol{F} = -\text{grad}\ \Phi$ and the force field can be represented as the "derivative field" of a scalar field, the scalar being called "potential." Many of the physical vector fields exhibit this characteristic although it is not always possible to give such a simple explanation. (In cartesian coördinates the vector notation $\boldsymbol{F} = -\text{grad}\ \Phi$ is equivalent to $F_x = -\dfrac{\partial \Phi}{\partial x}$, $F_y = -\dfrac{\partial \Phi}{\partial y}$, and $F_z = -\dfrac{\partial \Phi}{\partial z}$.)

As another example consider the flow of a liquid within a channel where the velocity $\boldsymbol{v}$ is the representative field vector. The integration $\int\int_0 \boldsymbol{v}{\cdot}d\boldsymbol{s} = \int\int_0 v_n dS$ over a closed surface gives, as is easily seen if the density is constant, the total flow through this closed surface. ($\int\int_0$ indicates integration over a closed surface.) Thus, if this integral van-

1. For all numbered references see list at end of paper.

ishes, as is usually the case, no liquid is accumulating or disappearing. An exception would be an underground source of water of unknown location so that only the increase beyond the balancing value could be observed. Again this regularity must imply a relation of the differential quotients and it can be shown that div $\boldsymbol{v} = 0$, a special form of the equation of continuity of flow. (In cartesian coördinates the vector notation div $\boldsymbol{v} = 0$ is equivalent with the scalar equation $\left.\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0.\right)$ But if the vector has no divergence, its field can be represented as the derivative field of another vector field such that $\boldsymbol{v}$ = curl $\boldsymbol{P}$, the new vector being called the "vector potential" in rather loose analogy to the scalar mother function introduced above.

The 2 types of fields are referred to as the potential field and the circuital field and their proper combination can produce any general field whatsoever. Field vectors for which curl $\boldsymbol{A} = 0$ and div $\boldsymbol{A} = 0$ admit of complete determination by the scalar mother function, the potential, defined through $\boldsymbol{A} = -$grad $\Phi$. Such fields are the most regular type and the most important ones in physics and engineering; their mathematical representation is the simplest and is usually summarized as "potential theory" proper, and constitutes the most extensively developed branch of mathematical physics.

## Potential Fields in Engineering

The overwhelming importance of potential fields for general physics and engineering may be illustrated by Table I where several branches of science are enumerated and some of their important fields of applications indicated. Such a table can by no means be complete and the references are restricted to a few outstanding contributions. Even so the bibliography shows the difficulty in attempting to treat a field so wide and varied. In anticipation of greater interest in applications to electrical engineering, stress has been laid upon applications in this particular branch and the fundamental books or treatises concerned with the mathematically related branches are included in the bibliography.

For the sake of simplification and uniformity of expression the general notation $\Phi$ for scalar potential and $\boldsymbol{A}$ for field vector shall be used throughout. The interpretation in terms of a particular branch appears evident if Table I is consulted.

In a true potential field it is easy to find orientation. The surfaces where $\Phi$ = cons are called *equipotential surfaces*, and they never can intersect each other. The field vector can be used to define *field lines* in such a form that the vector always is tangential to these lines. These curves represent the shortest path from higher to lower potential if the greatest rate of change is considered. It can easily be proved that field lines and equipotential surfaces must be 2 families of orthogonal geometries. One family being known, the other can be traced without trouble. For a potential field vector generally

$$\text{div}\, \boldsymbol{A} = s(x, y, z) \tag{1}$$

where $s$ is the distribution of sources and sinks assumed to be known. (A region of space where the divergence of the field vector does not vanish is called a source or a sink according to whether there is a positive or negative value of divergence.) Combining eq 1 with the definition of potential

$$\boldsymbol{A} = -\text{grad}\, \Phi \tag{2}$$

there is obtained generally

$$\text{div grad}\, \Phi = -s(x, y, z) \tag{3}$$

a linear differential equation of the second order, known as the potential equation. Its solution is usually obtained in 2 steps by first solving the homogeneous differential equation

$$\text{div grad}\, \Phi = 0 \tag{3a}$$

known as the Laplacian equation, and then determining the complete integral, *e. g.*, by the method of

**Table I—Table of Potential Fields**

| Branch of Science | Potential Function $\Phi$ represents | Field Vector $A$ represents | Important Applications | Reference numbers in list at end of paper |
|---|---|---|---|---|
| Electrostatics | Electrostatic potential | Electric field strength | High voltage problems<br>Cable theory<br>Transmission line theory<br>(Communication and power) | 1, 2, 6, 7, 9, 10, 11, 12, 15, 16, 18, 23, 24, 25, 30, 35, 36, 37, 38, 39, 46, 47, 48, 49, 50 |
| Electrodynamics | Current potential (same values as electrostatic) | Electric field strength | Ground currents<br>Electrolytic conduction<br>Current distributions | 1, 2, 6, 7, 15, 18, 40 |
| Magnetostatics | Magnetostatic potential | Magnetic field strength | Permanent magnets<br>Electrical machinery<br>Transmission line theory<br>Interference | 1, 2, 6, 7, 14, 15, 16, 17, 18, 19, 20, 21, 22, 31, 41, 51, 52, 53 |
| Thermodynamics | Temperature (isotherms) | Temperature gradient | Temperature distributions in solids, liquids<br>Heating and cooling of machinery<br>Current carrying capacity of cables | 2, 3, 6, 11, 32, 54 |
| Mechanics | Gravitational potential | Force | Gravitational problems | 1, 6 |
| Theory of elasticity | Stress function | Stresses | Torsion problems<br>Static stress analysis<br>Theory of deformations | 2, 4, 6, 55 |
| Hydraulics | Velocity potential | Velocity | Flow of liquids<br>Hydrostatics<br>Dam designs<br>Streamlining of vessels | 2, 6, 8, 13, 42 |
| Aerodynamics | Velocity potential | Velocity | Flow of gases<br>Streamlining<br>Aeroplane design<br>Profiling of wings | 2, 5, 6, 8, 42 |

variation of constants. If the field does not contain any sources or sinks one is immediately led to eq 3*a* which, therefore, represents the fundamental formulation of the potential problem.

Solutions of the Laplacian equation are known in great numbers. The difficulty in treating special problems is, however, not so much to find a general solution for eq 3*a* as it is to satisfy the particular boundary conditions. A general solution of eq 3*a* contains for each coördinate 2 independent integration constants and the problem is relatively simple as long as there are for each coördinate 2 boundary surfaces, at different fixed potential values, each expressible in one single variable. This means that only very idealized problems can be treated and in addition the boundary surfaces must have simple forms. Most of the practical problems, therefore, devoid of simplicity, are not amenable to direct mathematical treatment.

It is this situation, which, in view of the tremendous importance of potential fields, spurred the search for methods of field mapping by whatever means possible. Scanning the various methods available in potential theory they can be grouped as follows:

*a*. Experimental reproduction.
*b*. Graphical mapping.
*c*. Semigraphical mapping.
*d*. Direct mathematical solutions.
*e*. Direct mathematical approximation.
*f*. Conjugate functional methods.
*g*. Conformal representation.

On account of the broad scope, the following paragraphs will give a short critical survey of the methods enumerated, with references, special emphasis being laid upon the last 2 most recent and powerful mathematical tools.

## Experimental Reproduction

The functions $\Phi$ and $A$ are common to all potential problems. Analogies may, therefore, be drawn between any 2 branches of applications and if there is one potential field that can easily be set up at will in the laboratory, all the other fields can be pictured with it. Such a convenient reproducing standard is the electrolytic field, the field of the electric current in an electrolytic trough. The electrodes may be formed into any shape whatsoever, supplied with any potential value, preferably at medium frequencies (400 to 600 cycles) and the potential distribution explored with a probe by means of a potentiometer. Usually a direct cross-sectional graph of the equipotential lines can be obtained.

In this way reproduction of the electrostatic field is often obtained for problems in electronic tubes where several different potentials are applied and where the potential distribution is a controlling factor in the amplification and control characteristics.[9,10] In high voltage cable design this method is used to study the electrostatic field as well as the temperature distributions under varying conditions, simulating the dielectric constants and thermal conductivities by electrolytes and electrodes of different electric conductivities.[11,12] Quite recently another interesting example can be found in the reproduction of a hydraulic problem,[13] evaluating the pressure field on a dam.

Another experimental reproduction method was employed for study of magnetic field distributions in armatures and slots of electrical machines to assist in the proper design. The field lines are shown by finely distributed colored glycerine forced into water flowing between glass plates so that very clear photographs of the stream lines could be obtained.[14,21]

## Graphical and Semigraphical Mapping

Purely graphical methods have been developed chiefly for the electric and magnetic fields in space and for 2-dimensional arrangements. Having a good textbook available[15] it might seem superfluous to expand here were it not for the fact that usually no references are given to the original publications where much valuable information can be obtained.

Graphical mapping is essentially based upon the law of superposition, i. e., the fact that fields produced by a number of sources of vanishing dimensions superimpose upon each other without mutual effects. The fields of points and mathematical lines as sources are typical examples. Knowing the individual field picture the resultant for several sources can be easily drawn. The proper selection of field lines and equipotential lines may be guided by the flux principle devised by Maxwell,[16] who also gives examples for electric and magnetic fields.[17] Extensive history and literature on the subject may be found in the "Handbuch der Physik."[18]

In the case of 2-dimensional fields with any arrangements of given equipotential surfaces it is possible to combine certain mathematical properties of the potential field with graphical methods and secure field pictures otherwise not obtainable. Th. Lehmann[19] gave the fundamental theory and many applications to mapping problems of magnetic fields, so important, for example, in the design of large alternators,[19,21] in the computation of transformer leakage,[21] in the evaluation of mechanical forces,[21] and in special operating conditions of machines.[22] For the proper design of electric insulators of all types one needs the knowledge of the field distributions. The 2-dimensional case was developed by Lehmann,[23,29] and Mueller,[20] and the 3-dimensional case with rotational symmetry was suitably modified by Kuhlmann.[25]

The semigraphical methods are of utmost value in all design problems of large machines and high voltage apparatus, and probably constitute the tools most widely used for field mapping. Their disadvantage lies in the amount of labor involved to obtain correct field pictures, necessity for frequent redrawing, and the fact that each picture holds for one individual case only. Although the applications quoted here are in the vector fields of electrical engineering, these methods can be, and are, used for the other vector fields as listed in Table I.[2,5,8]

## Direct Mathematical Solution or Approximation

The direct methods are the ones usually treated in the textbooks, and will be found in the fundamental

references of the first part of the bibliography. The current journals of the various scientific and engineering societies publish many contributions to this special field of applied physics or applied mathematics. Any attempt to give a bibliography of these would be futile on account of the immensity of the subject. A very good general survey is given by Kellogg.[6]

As emphasized in the introductory part, the direct methods are applicable for simple boundaries only and solutions are known for the fundamental geometries in the various physical coördinate systems[1] in connection with the related orthogonal function systems.[6,35] Unfortunately it requires, in general, a series expansion to solve even simple potential problems which are in rather remote relation to practical problems, so that direct analysis seems a matter more of mathematical interest than of obtaining practical solutions. The semigraphical methods, in spite of their many disadvantages, have been preferred and are preferable from the engineering point of view, as long as acquaintance with the methods to be described in the following chapters was a rarity.

## Conjugate Functional Method

Assuming familiarity with the fundamentals of complex quantities a few fundamental relations will be given to show the usefulness and practicability of conjugate functions for engineering use.

If $z$ is the complex expression for the radius vector in a coördinate plane with origin $O$ (see Fig. 1),

$$z = x + jy = |z| \cdot \epsilon^{j\varphi} \tag{4}$$

then any mathematical function of $z$ may be written

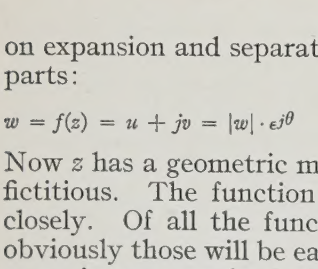


**Fig. 1. Complex variable and differentiation in the complex plane**

on expansion and separation into real and imaginary parts:

$$w = f(z) = u + jv = |w| \cdot \epsilon^{j\theta} \tag{4a}$$

Now $z$ has a geometric meaning; $w$ is, so far, purely fictitious. The function $w$ will be examined more closely. Of all the functions of complex character obviously those will be easiest to study which exhibit some inner organized structure. As shown in the introduction, structure has to do with rate of change. Consider the differential quotient and its common definition analogous to the case of a real variable

$$\frac{dw}{dz} = \frac{d}{dz} f(z) = \lim_{\Delta z \to 0} \frac{\Delta w}{\Delta z}$$

Since $\Delta z$, as part of $z$, is also complex, $\Delta z \to 0$ means an infinity of different possibilities of approach toward $P$ (in Fig. 1 only 3 such possibilities are indicated). A function $w$ which would give different values for its differential quotient depending upon the choice of $\Delta z$ cannot have much value for physical interpretation. Thus uniformity of $\lim \frac{\Delta w}{\Delta z}$ is demanded independent of the particular choice of $\Delta z$. Interestingly enough, this *one* condition, which is the only reasonable one to impose, leads straight to the class of "analytic" functions, the class which bears the closest relation to physical phenomena.

From this one condition the Cauchy-Riemann differential equations[26,27] can be derived:

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}, \quad \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x} \tag{5}$$

which restrict the variability of the real and imaginary parts of the complex function and, in fact, constitute an interrelation such that if $u$ is assumed, $v$ follows immediately.[28]

Furthermore, if eq 5 are differentiated, the first with respect to $x$, the second with respect to $y$ and both results are added, there is obtained

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0 \tag{6}$$

and similarly

$$\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} = 0 \tag{7}$$

which is the potential equation in 2 dimensions for a Cartesian system. Thus any analytic function of $z$ represents with its real and with its imaginary part the mathematical expression for possible potential fields in 2 dimensions.

Consider as a special case the function

$$w = a \log z = a \log |z| + ja\varphi = u + jv \tag{8}$$

(Logarithms given are natural logarithms, i. e., to the base $e$.) It is customary to call the absolute value of the radius vector

$$|z| = r = \sqrt{x^2 + y^2}$$

and $\log r$ must represent a potential field. It is easily identified with the electric field of an infinitely long wire uniformly charged, the potential of which is given by[1,6,7]

$$\Phi = \frac{q}{2\pi\Delta} \cdot \log r = u$$

Here $q$ is the charge per unit length and $\Delta$ the absolute dielectric constant.[29] The constant follows as

$$a = \frac{q}{2\pi\Delta}$$

Since the imaginary part of $w$ also satisfies the potential equation it is interesting to ask what it represents. Putting

$$v = \text{cons}$$

the lines $\varphi$ = cons, or radii vectors are obtained, which are the field lines. In general $v$ = cons leads to a family of curves orthogonal to $u$ = cons, i. e., to the equation of the field lines and is, therefore, called the *flow function*. It is this relationship which

accounts for the importance of complex functions in potential theory and which has led to the designation conjugate functions for $u$ and $v$ in the combination $w$.

Let the general rule be accepted of considering the real part of an analytic function as a real potential function

$$Re(w) = u = \Phi$$

and the imaginary part as the orthogonal flow function

$$Im(w) = v = \Psi$$

which defines the field lines. On account of eq 6 and eq 7 it may be asked what is represented by

$$Re(jw) = -v = \Phi$$
$$Im(jw) = u = \Psi$$

In this case, obviously, the field lines are the circles and the equipotential lines the radii vectors—the magnetic field of an infinitely long linear current is obtained.

The case given by $r = 0$ is rather embarrassing in the mathematical as well as in the physical sense, since nature must present herself at least to our senses in 3-dimensional and probably finite space; and to

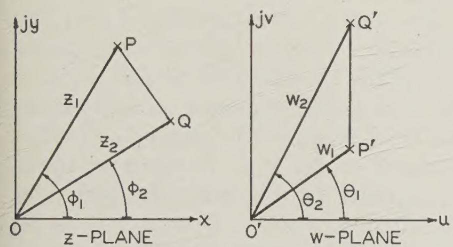


**Fig. 2. Correspondence of points in 2 complex planes**

have log $r$ at the point where $r = 0$ assume a value $(-\infty)$ is a mathematical absurdity, but this cannot be prevented on account of our limited tools. To avoid these difficulties which always arise when it is attempted to follow the mathematical pictures of physical phenomena to the limits, $r = 0$ is simply excluded and its infinitesimal neighborhood—whatever that may mean—is defined as a "singularity," a plain confession of the limitations. Nevertheless, the picture can thus be saved for finite value, of $r$, which is all that can be verified experimentally anyway. (A similar consideration ought to be given for the region $r = \infty$.)

The conjugate functions log $z$ have been shown to represent at finite distances the fields produced by "source lines" and "circuital axes," according to the choice of $u$ or $v$ as the potential function. The most important conclusion is that the law of superposition can be applied for several such lines or axes and leads to the functional correlate to the pure graphical mapping method. Much use has been made of this functional construction of fields for electrical problems involving the electrostatic field of grids in vacuum tubes,[30] for the magnetic fields of any number of parallel wires carrying current with or without iron,[31] for the temperature distribution in multiconductor cables,[32] for the capacity effects in multiconductor cables,[33] for the flow of liquids,[34,2] and other problems.

Knowing the particular potential function the field vector is obtained according to eq 2 as

$$A_x = -\frac{\partial\Phi}{\partial x}, \; A_y = -\frac{\partial\Phi}{\partial y}$$

or expressed as a complex quantity

$$\bar{A} = A_x + jA_y = -\left(\frac{\partial\Phi}{\partial x} + j\frac{\partial\Phi}{\partial y}\right) \tag{9}$$

In this form $\bar{A}$ is often said to have the character of a "plane vector." This is not only misleading but accounts for unexplainable discrepancies in complex

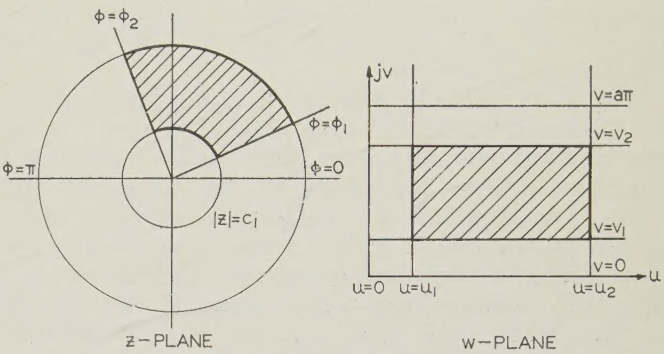


**Fig. 3. Conformal representation effected by the analytic function w = log z**

integrations. The notation $A_x + jA_y$ is but one possible combination of the 2 components which, properly understood, is more convenient than the vector notation now universally used in vector analysis.

## Conformal Representation

The functional relation $w = f(z)$ can be interpreted in another interesting manner. Equation 4$a$ has essentially the same form as eq 4 and obviously no objection could be raised to considering $w$ as a complex representation of points $(u + jv)$ in a separate plane of its own. As in Fig. 2, a $w$-plane and a $z$-plane can be correlated so that any point $P(z_1)$ or $Q(z_2)$ corresponds to a point $P'(w_1)$ or $Q'(w_2)$, respectively, and any array of values $z$ is correspondingly represented by an array of values $w$. This transformation of an array in $z$ into one in $w$ is completely determined by $f(z)$ the transforming function and, therefore, depends in its qualities upon $f(z)$.

If now $w = f(z)$ is an analytic function its derivative $\frac{dw}{dz}$ will be a definite function of $z$ only

$$\frac{dw}{dz} = f'(z) \tag{10}$$

and will not depend upon $dz$ by definition. Writing $f'(z)$ and $dz$ as complex quantities in polar form

$$f'(z) = M \cdot \epsilon^{j\mu}, \; dz = ds \cdot \epsilon^{j\beta} \tag{11}$$

there results for eq 10

$$dw = (M\,ds) \cdot \epsilon^{j(\mu+\beta)} = dS \cdot \epsilon^{jB} \tag{12}$$

Equation 12 shows the peculiarities of the transformation: the magnitude of $dw$ bears a ratio $M$ to

the magnitude of $dz$, which is constant for any one point whatever the direction of $dw$ might be, but varies from point to point (since $M$ is a function of $z$ only); the direction of $dw$ is rotated with respect to that of $dz$ by an angle $\mu$, again constant for any one point but varying from point to point. These 2 properties mean a geometrical transformation maintaining proportionality in infinitely small regions with preservation of all angular relations but effecting a complete deformation in finite dimensions. The main feature is that angles remain the same in both planes, since rotation by a constant angle takes place at each point, a characteristic which is responsible for calling this process a *conformal representation*,[36,2] and making it a powerful tool for mathematical analysis.

The potential field with the 2 orthogonal families of curves, equipotential lines and field lines, will retain this orthogonality when conformally represented but may change the shape of the lines entirely. Proper application of conformal representation should be suitable to reduce rather complicated potential fields to very simple ones which have already been fully explored, and transforming the knowledge of the simple field back into the original problem should solve this by transformations only. Since the only condition is that $f(z)$ be an analytic function, a study of the transformations afforded by various such functions should yield a rich crop of solutions to possible problems and those of practical value could be selected.

The function $w = a \cdot \log z$ from eq 8 can now be interpreted as a conformal representation. From

$$u = a \log |z|, \; v = a\varphi$$

it is obvious that

$$u = \text{cons}, \; |z| = \text{cons}$$
$$v = \text{cons}, \; \varphi = \text{cons}$$

or the orthogonal set of coördinates in the $w$-plane transforms into the orthogonal set of polar coördinates in the $z$-plane. The shaded areas in Fig. 3 are an illustration of this transformation; the corresponding values are

$$u_1 = a \log c_1; \; v_1 = a\varphi_1$$
$$u_2 = a \log c_2; \; v_2 = a\varphi_2$$

Obviously a complete annular ring from the $z$-plane would be a finite rectangle of height $(a \cdot 2\pi)$ in the $w$-plane and if $|z|$ would cover the total range $0 < |z| < \infty$, the infinite strip $-\infty < u < +\infty$ would be its conformal representation.

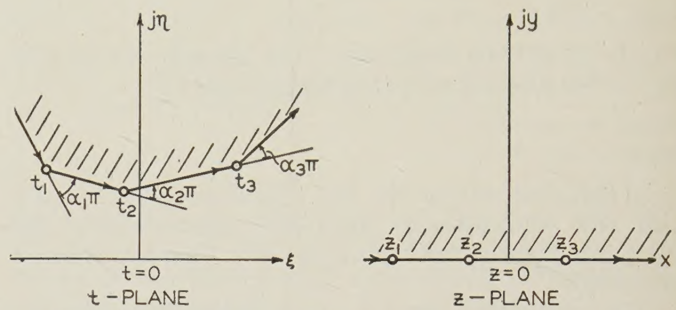


**Fig. 5. Conformal representation of polygonal region**

An example for this case is shown in Fig. 4 and the correspondence is obvious. One might say the plane condenser of the $w$-plane is stretched out into 2 planes lying side by side in the $z$-plane, compressing and lengthening the field lines accordingly. Mathematically the 2 planes $\Phi = \Phi_1$, $\Phi = 0$ seem to meet at the origin of the $z$-plane which from the physical point of view would seem absurd. But at $z = 0$ eq 8 gives a value for $w$ which can be shown to be singular. Approaching $z = 0$ from left brings $w \rightarrow (-\infty + ja\pi)$, approaching $z = 0$ from the right gives $w \rightarrow (-\infty + j0)$, so that there is a physicomathematical discontinuity, $\frac{dw}{dz}$ at the point where $z = 0$ has no distinct value, and the representation cannot be a conformal one there. This solves the dilemma, since it requires the exclusion of $z = 0$ from the conformal region by a small half circle, representing an infinitesimal field line, and makes the strip in the $w$-plane finitely bounded on the left-hand side as shown in Fig. 4, where the last field line corresponds to the infinitely small half circle. This example may serve to illustrate some of the difficulties encountered in conformal representation which, while not serious in themselves, should serve as a reminder to always examine carefully the fundamental statements before proceeding further.

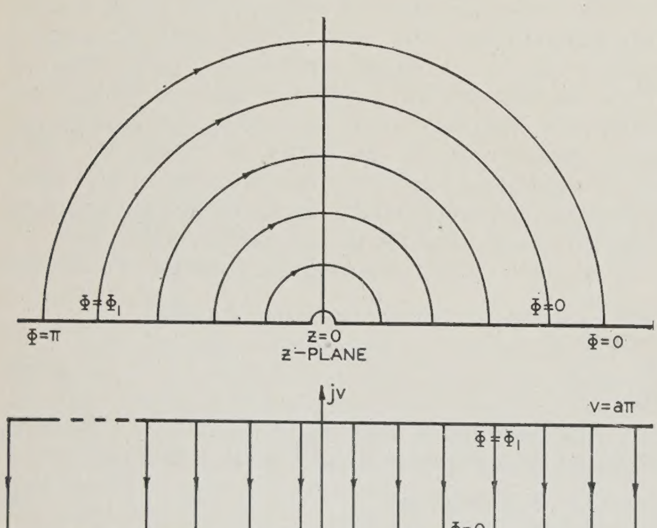


**Fig. 4. Conformal representation of the upper half z-plane into an infinite strip in the w-plane. Note exclusion of singular point z = 0**

Again, many examples of applications in all branches of science are available in the literature, such as the evaluation of the amplification factor and similar characteristics of vacuum tubes with small grid wires,[37,7] or with grid wires of finite diameter,[38] the capacity problems of bus bars,[39] the flow of current in a circular disk,[40] the determination of the magnetic field distribution in machines,[41] the flow of liquids and gases around cylinders and similar bodies,[2,39] profiling of wings of airplanes,[2,5,42] and other problems.

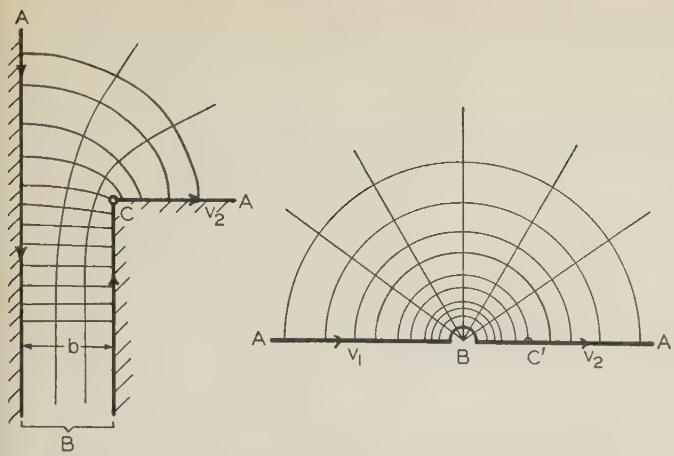


**Fig. 6. Illustration of the electric field distribution for a rectangular edge opposite a plane, and its conformal representation upon the upper half plane**

## Conformal Representations of Polygonal Regions

One of the most important theorems in the domain of complex functions can be stated about as follows: Any finite polygonal region not containing singularities can be conformally represented on the upper half plane so that the boundary of the polygon is uniquely transformed into the real axis.[43,44] The function which performs this is given by[29,26]

$$z = C_1 \int \frac{dt}{(t-t_1)^{\alpha_1}(t-t_2)^{\alpha_2}\ldots(t-t_n)^{\alpha_n}} + C_2 \tag{13}$$

where $C_1$, and $C_2$ are 2 complex constants specifying the proper situation of the $z$-plane with respect to the $t$-plane and fixing the scale in the $z$-plane; $t_1, t_2, \ldots t_n$ are the vertices of the polygon, and $\alpha_1\pi, \alpha_2\pi, \ldots \alpha_n\pi$ the supplementary angles of the polygon at these vertices (see Fig. 5). The region represented is alway at the left-hand side if progressing along the boundary from $t_1$ to $t_2$ or $z_1$ to $z_2$, respectively.

Even a brief account of this invaluable theorem would take up more space than can appropriately be expected. Therefore, only a few remarks will be made and more emphasis placed on enumeration of some important applications. To make the representation a determined one 3 points in the $z$-plane must be arbitrarily assigned as to their position; conveniently 3 vertices will be chosen. All the other vertices as well as $C_1$ and $C_2$ have to be determined by proper correspondence of points and integrations over the lengths of the polygon sides in the $t$-plane. This usually presents one of the main difficulties in using Schwarz's theorem, as eq 13 is referred to, since the integration indicated there must be performed. This often leads to elliptic integrals and functions for even the relatively simple cases, and to hyperelliptic and unsolvable integrals in many important cases. Thus the method has serious limitations and various attempts have been made to eliminate these restrictions by approximation with polynomial expressions and the like.[26,28]

Notwithstanding the mathematical difficulties, where solutions are possible, they are obtained in one of the most elegant methods of mathematics. Imagine that instead of solving a differential equation of the potential with boundaries not amenable to explicit expression, except as sectional straight lines, one has but to transform the whole region into the upper half plane, join a transformation as Fig. 4 shows (and as was discussed in the preceding section) and there is obtained the field of the plane condenser. Of course, to utilize the homogeneous field properly it will be necessary to arrange the transformation from the $z$-plane to the $w$-plane so that the potential values are constant on the lines $v$ = cons; Fig. 4 is only a very simple, special case of 2 potentials.

It remains now to illustrate the practical value by deriving the expression for the field vector. In the $t$-plane, where $t = \xi + j\eta$, the potential function $\Phi$ will be a function of $\xi$ and $\eta$ and follow Laplace's equation. The field vector, therefore, must be

$$\boldsymbol{A} = -\text{grad}\,\Phi = -\frac{\partial\Phi}{\partial\xi} - j\frac{\partial\Phi}{\partial\eta} \tag{14}$$

Since, however,

$$\frac{dw}{dt} = \frac{dw}{dz}\cdot\frac{dz}{dt}$$

for the complete conformal representation (where $\frac{dw}{dz}$ transforms similar to Fig. 4 and $\frac{dz}{dt}$ according to eq 13) $w$ must be an analytic function of $t$ and

$$\frac{dw}{dt} = \frac{\partial w}{\partial\xi} = \frac{\partial u}{\partial\xi} + j\frac{\partial v}{\partial\xi} = \frac{\partial v}{\partial\eta} + j\frac{\partial v}{\partial\xi} \tag{15}$$

may be used. The first relation states the independence of the differential quotient on the way of approach and the last 2 terms involve the first eq 5. But eq 15 has close resemblance to eq 14, if, as in Fig. 4, the $v$-lines are identified with equipotential lines. One, therefore, simply has

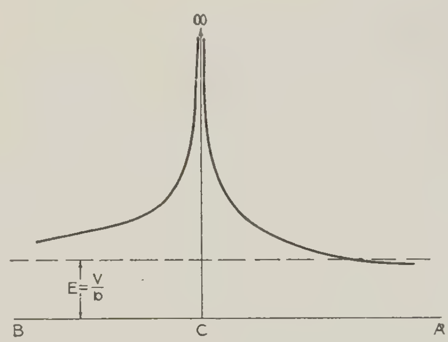


**Fig. 7. Variation of the electric field strength along the rectangular edge BCA, computed according to eq 14**

$$\boldsymbol{A} = \text{conj}\left[j\frac{dw}{dz}\cdot\frac{dz}{dt}\right] = -\frac{\partial v}{\partial\xi} - j\frac{\partial v}{\partial\eta}, \tag{16}$$

where conj symbolizes that all imaginary parts within the brackets shall be taken with their conjugate (negative) values. Thus, the field vector at any point in the $t$-plane, the original arrangement, is explained in terms of the transforming function eq 13 and the required joint transformation.

As an illustration, in Fig. 6 is shown the field distribution in $t$-plane and $z$-plane for a rectangular edge opposite a plane. The field lines concentrate

at the edge $C$ and a high value of field strength has to be expected there. In Fig. 7 is given the variation of field strength $\boldsymbol{E}$ as computed according to eq 16 along the surface of the rectangular edge $BCA$, and it can be seen that near the edge $C$ the value of $E$ increases rapidly and, mathematically, reaches infinity. To avoid such highly stressed regions in electric fields, where breakdowns would occur first, it is necessary to round off the corners. Minimum values of the radius of curvature can be estimated from the field picture or computed by approximation methods.[45]

Many other applications have been made among which may be mentioned the design of high voltage insulators,[46,36] and of high voltage transformers,[47,48] the field distribution at the edges of a plate condenser[49] and its application to the proper shaping of the electrodes in order to avoid breakdown at very high voltages,[50] and numerous other electrostatic problems. The magnetic field distribution in the slots of dynamos[51,52] has been investigated as well as in large generators, where the leakage problem is predominant.[53] The temperature distribution in slots of high speed turbine-alternators is another interesting example[54] and finally there may be mentioned the solution of torsion problems[4] especially in the case of the angle iron.[55]

Although the field of conformal representation is the subject of many articles of which only a few have been included in the references which follow, the subject is as yet rather new. Applications to many problems are possible and altogether desirable, since a general solution can be obtained which would permit general conclusions and give analytic methods for improving designs and constructional features.

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# Characteristics of a Group of Engineers

**An analysis of the characteristics of a group of development and research engineers is presented in this paper. From this analysis an attempt is made to point out the weaknesses that were responsible for some men being released during this period of abnormal business conditions, and, conversely, to show the elements of strength that permitted others to be retained. Such an analysis should be helpful not only to the young engineer entering industry and to the teachers who have prepared him, but also to his employers.**

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DURING the past few years of economic stress, employers have found it desirable to study and analyze the value of their individual employees as they never have done before. The necessity for considerable reductions in personnel has resulted in the release of many engineers with adequate technical training because it was judged that those men, although doing their work with reasonable efficiency, were, nevertheless, inferior to others associated with them.

Just as abnormal conditions of loading with consequent failure have resulted in making available valuable data on the strength of various mechanical structures, so perhaps a study of the abnormal requirements imposed on those employees who have not weathered the depression with their jobs intact may reveal weaknesses in a group that before had not been appreciated. Similarly, a study of those who have survived may indicate the elements of strength that permitted their survival.

It has been the author's privilege for some years to introduce a considerable number of research workers to their first regular jobs, and it has been his misfortune to assist some of them involuntarily to relinquish those jobs. It would seem to be interesting and perhaps valuable to examine critically and classify the causes that led to the release of those particular men rather than some of their fellow workers. Many of the men released were only slightly inferior to their associates who remained and in some respects were frequently superior, though a few were obviously misfits and had been retained only because of the scarcity of suitable technical help. Were their faults or weaknesses attributable to lack of satisfactory training, to the fact that they were in the wrong kind of work, to personal characteristics, or what were their major difficulties?

There has been much discussion and criticism lately of the curriculums of engineering schools. Can those men who were released legitimately lay their difficulties to unsuitable training, either of type or quality?

Many of these individuals were selected for their particular jobs by men who have specialized in that sort of thing, and they were under continual observation for a year or more during special training before they were assigned to their final positions. Were the assignments poorly made and was the specialized training not satisfactory? Again, as the result of inheritance or unsuitable environment (in or out of school), did these men have personal characteristics that stood in their way and that might have been improved by serious self-analysis and perhaps by sympathetic external guidance?

It is hoped that this analysis may assist in answering these questions and serve as a guide for young technical students and graduates. It also may be of assistance to those who select and give special training to such young men.

This analysis is confined to men who were engaged in research and development work, and might not apply so well to those in design and commercial activity. They are all men who the author has known for several or many years and with many of whom he has worked and played. The analyses of the reasons for their release, therefore, should be fairly reliable, especially since many of them were checked by others. It should be emphasized that none of these men are failures, but only that their fellows in similar work were judged to be more valuable. Many of these men very shortly were reabsorbed by industry, either by the Westinghouse company or some other concern, in a different capacity and some with better financial rewards than they previously had received.

Only technically trained men are being considered in this analysis and all were active experimenters, that is, none were in purely executive or consulting positions. Also laboratory assistants, whether on technical or manual work, are not included.

Points to be emphasized as a result of this study are these:

1. The great importance of temperamental traits in the success or failure of research and development engineers perhaps is not fully appreciated. More attention should be paid to these traits in the selection, guidance, and early training of prospective engineers.

2. Students should be taught the importance of temperamental traits and personality factors and how these factors will affect their future success even in noncommercial fields of work. This should be started at an early age.

3. Technical schools should consider the possibility of group activities which will involve several students working together on a single project. The weaknesses of an individual as a member of a group should be pointed out to him; and if his faults are such that they cannot easily be remedied, the student should be guided into

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activities where his individualistic traits will not be too much of a handicap.

4. Less emphasis in the schools should be laid on obtaining high marks in abstract studies and more on fitting the individual for his life work, taking into account his inherent temperamental and mental peculiarities and limitations. This will require a certain amount of individual work on the part of the instructors which may not fit in well with the present American method of mass production of technical school graduates.

5. There seems to be a definite correlation between success and induction into industry through a student training course

## Analysis of Men Released

The late B. G. Lamme is reported to have stated once that according to his observations, an engineer seldom failed because of deficiencies in technical knowledge, but usually because of some personal characteristic. This may profitably be kept in mind in studying figure 1 which is based on the analysis of the traits of men released since 1929.

It should be understood that each individual may and usually does have more than one point of weakness as will be discussed in more detail later. Each person, therefore, may come under 2 or more different classifications and under several items per class. These items are probably not in accordance with good psychological practice but they do represent the common types of criticism by which individuals often are judged. The "antisocial factors" are those that, if properly controlled at an early enough age, might have been improved. They are, of course, the factors that limit one's effectiveness in group activities. It may be wondered why "unimpressive personality" appears here instead of under "personality factors." It is believed that if an unimpressive person would exert himself a little in an effort to become interesting and to make himself noticed, he readily could eliminate this trait.

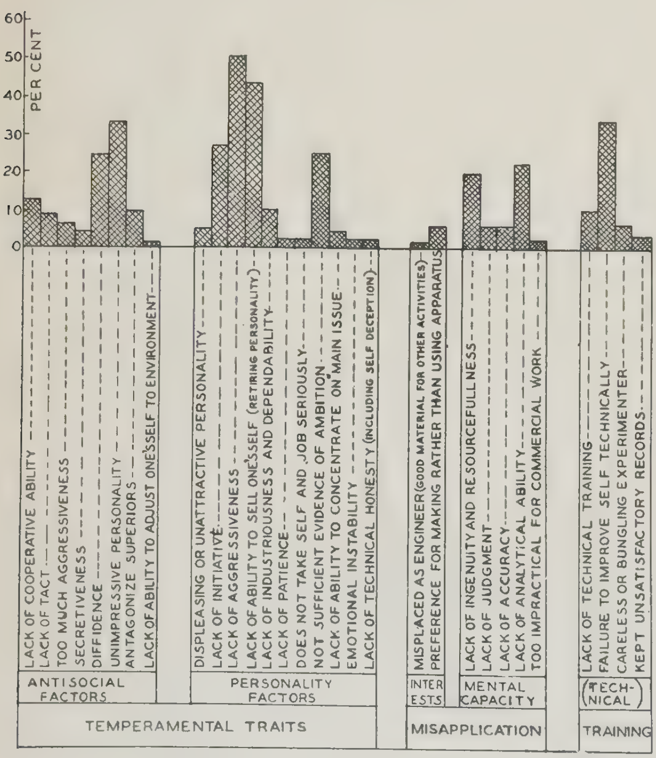


**Fig. 1. Faults and weaknesses of men released**

The percentages refer to the number of engineers deficient in the particular quality considered, based upon the total number released

It also may be questioned why "displeasing or unattractive personality" appears under "personality factors" instead of "antisocial factors." The reason is that a person may be displeasing or unattractive in spite of the fact that he may make a considerable conscious effort to be quite the opposite. In other words, he may be quite the reverse of antisocial in his desires and intentions.

The "inability to adjust oneself to his environment" is a difficulty experienced chiefly by foreigners whose training and background may be quite different from those in the United States. The items under "temperamental traits" and "misapplication" are largely inherent characteristics resulting from heredity and environment. Some of them could be altered considerably by proper supervision at an early age. Some never could have been altered appreciably. Most of them can be modified very little after a man has reached maturity.

It is felt that the characteristics under "misapplication" may interfere seriously with a man's success as an engineer though the lack of some of them might not be an important handicap in other lines of activity. These are the factors that should have been given particular consideration before a student took up the study of science or engineering. It is particularly unfortunate when a man is trained for engineering and his chief interest and capabilities lie elsewhere. It is probable that many cases of misapplication are avoidable.

Faults under "training" are believed to be due largely to weaknesses in the secondary and technical school education, though even here inherent individual characteristics will cause large variation.

It is interesting to note that the "temperamental traits" form such a large percentage of the causes of failure. The "antisocial factors" do not constitute a very large percentage, but they must be important in such a group as the one being considered here since nearly all research and development work of a large company necessarily must be of a coöperative nature. That the percentage of failures due to these factors is no larger is probably because in engineering and scientific schools and colleges coöperative activities have an important place. A "noncoöperator" is likely to be unhappy and eliminates himself from school or is removed arbitrarily before he finishes his technical training. The term "coöperative ability" is used to include success in getting along not only with those on an equal footing or in other allied activities, but also with one's subordinates as well. In the United States at least, it seems to work best when dealing with creative activities to consider one's subordinates as partners who are free to contribute ideas and not merely to carry out instructions. An executive who cannot work this way is probably not getting the most out of his subordinates.

"Diffidence" and "unimpressive personality" go together usually and are fairly large. It may be that some men are conscious of these defects and are guided into research because they believe that they

**Table I—Summary of Faults of Men Released**

| Characteristic | Per Cent of Men With at Least One Fault Under the Particular Characteristic | Per Cent of Men With Faults of One Type Only* |
|---|---|---|
| Temperamental | 84 | 37 |
| Misapplication | 45 | 6 |
| Training | 37 | 2 |

* There may be several items under one type.

will not be so handicapped in this type of activity, or it may be simply that they feel happier where social contacts are not so frequent or necessary.

The item "antagonizing one's superior" perhaps merits a moment's consideration. A man may be quite successful with one boss and a failure with another. It may be the fault of both or neither. Sometimes 2 strong personalities cannot get along together. Probably the only satisfactory solution is a separation and the sooner the better. Under "personality factors" the 2 big items are "lack of aggressiveness" and "lack of ability to sell oneself," the former showing that more than 50 per cent of the men had this failing. At first glance these 2 factors might be considered to be practically identical. This is not true although the majority of persons who have one of these failings also have the other. A man may be very quiet and nonaggressive and yet so conduct himself as to convince others of his capabilities and value. A man also may be aggressive, of course, without convincing others of his worth. It may be noted that "lack of initiative" and "lack of evidence of ambition" are the next 2 important items in this class. Without initiative a person will not be very valuable in most kinds of research, and if he does not display this quality he is in grave danger of being displaced. "Lack of evidence of ambition" is certainly a handicap. Any normal executive likes to see his subordinates display a reasonable amount of ambition either in the way of leadership or in establishing technical or scientific reputations for themselves. Without such an incentive a man is probably not working as hard and effectively as he should. The other items under "personality factors" are obvious and of minor importance from a percentage standpoint.

In considering the factors under "misapplication" and "training" it should be remembered that many of these men previously had been subjected to a very rigorous elimination process before being assigned to their particular research activities. A few had been hired when technical labor was scarce, and although known for some time to be somewhat unsatisfactory had not been eliminated previously because of the difficulty of replacing them with better material. Apparently very few were misplaced from the standpoint of interests. One or 2 undoubtedly would have been more successful in commercial activities and some would have been happier as artisans or designers. Several men were judged to fall in the "misapplication" class because of inherent limitations in "mental capacity." These limitations definitely prevented these men from going very far in their chosen profession. Earlier in life they should have been guided into activities in which these particular characteristics were not so essential.

A considerable number was lacking in "ingenuity and resourcefulness," which of course is a serious handicap, and a slightly larger number was lacking in "analytical ability." It is possible for a student to graduate from many technical schools with fairly good marks even if he be deficient in these qualities. It is very difficult, however, for him to make a success in research or development work without them.

Under "training" the one large item is "failure to improve self technically." This refers to study and reading beyond that just sufficient for the job immediately at hand. Such study is essential if a man is to keep up with new developments and continue to be valuable under changing conditions. Failure in this respect is due to laziness, lack of ambition, or sometimes to family or financial cares and worries. If a person has sufficient inherent scientific curiosity properly developed by suitable training, this seldom will be a serious fault.

Table I, taken from the same data as figure 1, gives some further interesting comparisons. It is interesting to note that 17 per cent had faults of all 3 major types. This table indicates very clearly that the temperamental faults constitute a large percentage of the total. It is particularly significant that

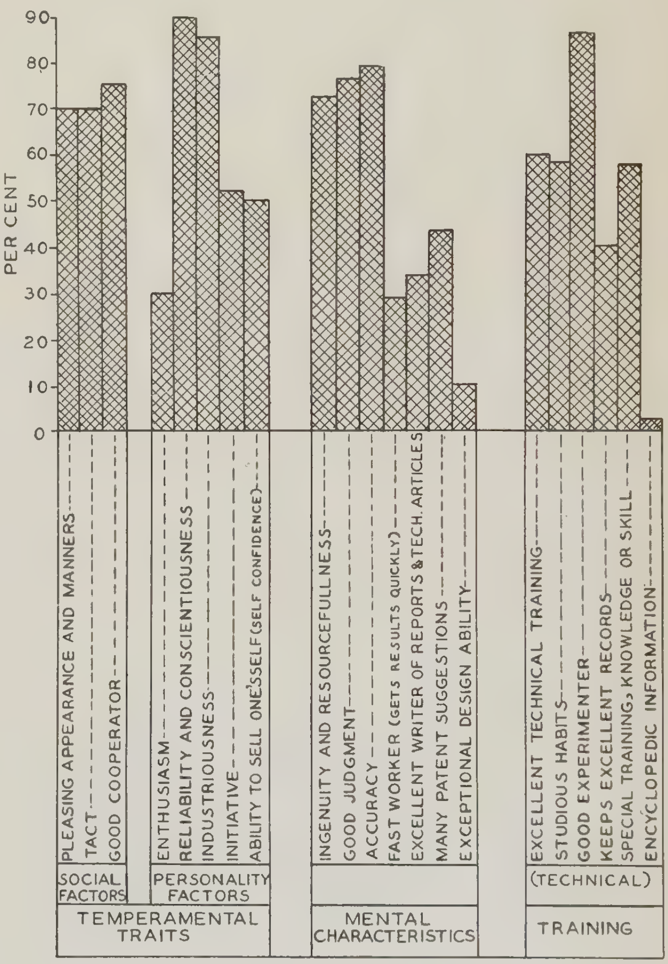


**Fig. 2. Qualities in which the men retained excelled**

The percentages refer to the number of engineers that excelled in the particular quality considered, based upon the total number retained

37 per cent of those men who were released had faults of this type only. It is also important to note that 84 per cent had temperamental faults of one kind or another. A considerable number was classed with characteristics under "misapplication and training," but it should be realized that the temperamental faults that many of these individuals also had were chiefly responsible for their release.

When the author attended technical school, he was led to believe, by inference at least, that to be a success the one thing necessary was to study hard and master the fundamentals of science and technology. The development of personality traits and the correction of temperamental faults scarcely were mentioned and certainly were not stressed. Perhaps more could be done by the schools in the formative period to bring home to the students the importance of their relations to their fellow men, not from a social standpoint but as a means of holding their jobs and advancing in their chosen profession. After a man becomes older it usually is too late to influence appreciably these characteristics.

### Analysis of Men Retained

Now the other side of the picture will be presented. So far only those men who were released have been considered; it may be just as profitable to examine those who weathered the storm and attempt to determine what particular elements of strength enabled them to do so. Were they especially well trained? Did they have particularly pleasing personal characteristics which caused them to be especially favored? Did they have specific information or abilities which would make them hard to replace, or to what could they attribute the fact that they were among the more fortunate?

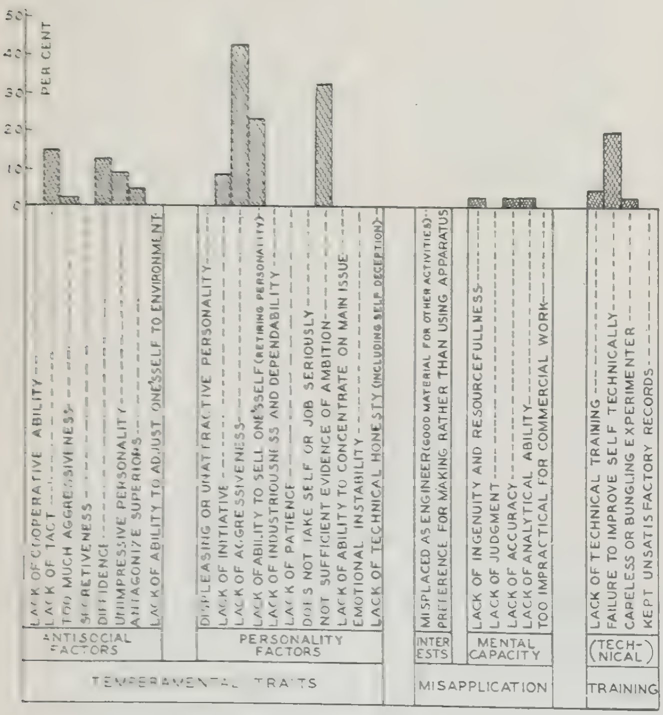


**Fig. 3. Faults and weaknesses of men retained**

The percentages refer to the number of engineers deficient in the particular quality considered, based upon the total number retained

**Table II—Summary of Limitations of Men Retained**

| Characteristic | Per Cent of Men With at Least One Limitation Under the Particular Characteristic | Per Cent of Men With Limitations of One Type Only* |
|---|---|---|
| Temperamental | 78 | 24 |
| Mental capacity | 24 | 2 |
| Physical limitations | 4 | 0 |
| Training | 40 | 6 |

* There may be several items under one type.

This classification is somewhat different since it deals with favorable qualities rather than with faults. It should be realized that a man may have serious faults that would have lead to his dismissal were it not for the fact that his virtues far outweighed them. This will be discussed later. Figure 2 gives an analysis of the favorable traits that made the men retained valuable. It would be expected that the "mental characteristics" and the "training" factors would be high, but it should be noted also that the "temperamental traits" are also fully as high. The "social factors" must be high because modern research on a large scale must be a cooperative activity and the ability to get on with one's fellow men is essential.

The "personality factors" are also very important. It is especially interesting to note that "reliability and conscientiousness" and "industriousness" are so high. If a man does not have these qualities he will not last long in these times unless he has some other outstanding qualities. It may seem surprising that enthusiasm is so low. Some of the best investigators go about their work quietly and never display marked outward signs of enthusiasm. Perhaps one of the most serious weaknesses of the average research investigator is his difficulty in interesting others in the results of his work. This is perhaps partly because of his characteristic of not displaying enthusiasm. He tends to be conservative because he realizes the difficulties in commercializing the results of his investigations.

Under "mental characteristics," ingenuity, resourcefulness, good judgment, and accuracy all rate high as they should, or these men would not have survived. Speed is not nearly as essential and rates somewhat low. Of course, speed is desirable, but not at the expense of accuracy.

Engineers are notoriously poor at writing reports and technical articles. That even 34 per cent of the men retained rate high is a pretty good showing.

Under "many patent suggestions" are included those who have averaged 2 or more per year. Some men have averaged many more than that. On the other hand, many very valuable research men seldom make a patent suggestion. Work of an analytical character may never result in a patentable product.

Except for a few special activities "exceptional design ability" would not be required. If many research men had this trait to a marked degree they probably would be misplaced.

The items under "training" are all high except the last, though there could well be some improvement in

the item of keeping records. A man who has an encyclopedic type of mind is likely to be weak in other desirable traits, particularly ingenuity. This percentage, therefore, is found to be low. If a man knows that certain information is available and where to find it, that is all that is essential.

It should be noted that all of the most important qualities for this group rate very high. A more detailed analysis would show that if a particular individual is not very strong in one or more of these items he makes up for the deficiency by strength in others.

All these men have received ratings in one or more items in each of the 3 main classes with the exception of 2 individuals who received ratings in 2 classes only.

### Faults of Men Retained

As previously mentioned, some of the men retained have serious faults, but their favorable characteristics or abilities were so great that they were not dismissed. An analysis of this group under the same classification as for those released is given in figure 3. As might be expected, the patterns of figures 1 and 3 are somewhat similar, but the percentages for those retained are considerably less, or even zero for some traits.

It is particularly interesting to note that the "misapplication" items are reduced to a very low value, as should be the case if the process of elimination were carried out properly. That there should be *any* such cases is due to exceptional conditions which need not be discussed here.

The importance of "coöperative ability" is shown by the fact that the lack of this trait appears as zero in figure 3.

Only 2 items are larger in figure 3 than in figure 1, namely, "lack of tact" and "not sufficient evidence of ambition." A man may be lacking in tact and still be so valuable that his superiors will tolerate him because of his strong positive virtues. This is a handicap to advancement however, as will be considered later.

A man may be very useful in his present situation even if he does not display evidence of ambition, although he doubtless would be a better worker if he were more ambitious. This trait also should be considered later with reference to the data of figure 4.

One more factor under "temperamental traits" that perhaps should be noted especially is that the item "lack of initiative" is much lower in figure 3 than in figure 1.

It is evident from a comparison of figures 1 and 3 that while men may have serious faults and still retain their positions, these faults play a large part in the choice of those to be eliminated in times of stress and are probably nearly as important as their valuable traits.

### Limitations of Men Retained

There is another analysis of those who survived the depression that can be made to advantage. Most normal men have certain ambitions and would like to advance as far as possible in their profession. Some wish for executive responsibility and others wish to be consultants or experts in some particular field. What limitations do these men have that may hinder their advancement? Such an analysis is, of course, somewhat speculative, particularly with reference to the younger men. The results of such an attempt are given in figure 4. The items follow fairly closely those of figure 1 with the elimination of some that did not apply since men with those characteristics would not have survived anyway. A few items have been added which were not needed for the data of figure 1.

The "antisocial" percentages are much lower than for those who were released, and some values are zero as would be expected. The "personality factors" rate rather high, particularly "lack of aggressiveness." If a man does not push himself it is unlikely that someone else will perform this service for him. It is interesting to note the considerable percentage who display no appreciable evidence of ambition. This is probably a fairly true picture since there are certainly a good many educated people who, if working in pleasant surroundings, are quite content to let things drift along as they are.

"Mental capacity" and "physical limitations" are quite small in percentage and need no particular comment.

Under "training," the "failure to improve self technically" is tied up to a considerable extent with "lack of ambition." It is perhaps a species of laziness and certainly denotes a lack of curiosity without which no research man is likely to go far.

There are certain "specialists" whose interests are so narrow that they are not fitted for executive duties involving the direction of several kinds of activities

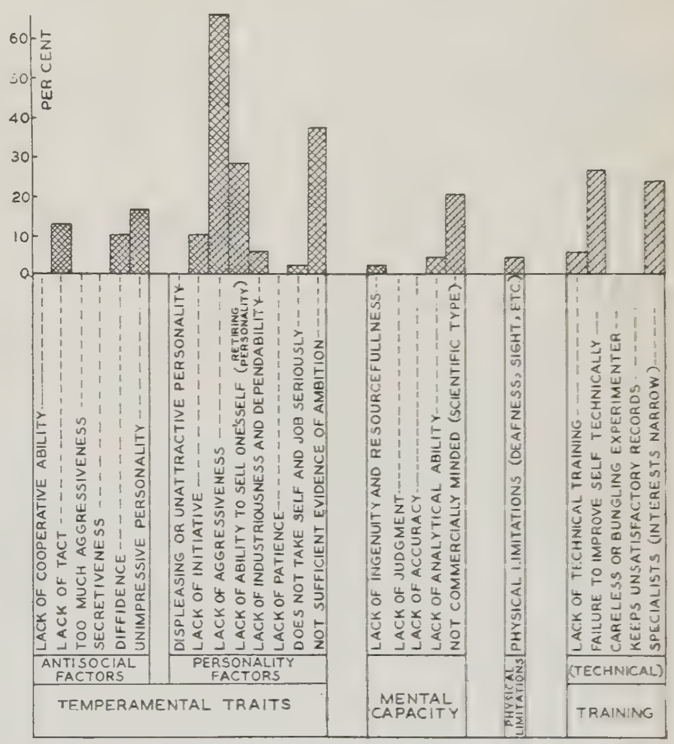


**Fig. 4. Qualities that would tend to limit the advancement of men retained**

The percentages refer to the number of engineers limited by the particular quality considered, based upon the total number retained

and who cannot become regular consultants because the demand for their services would be too limited. These men usually are reasonably content with their existing lots in life.

Some further comparisons may be valuable. These (table II) are taken from the data of figure 4 and therefore refer to the limitations to advancement. As may be seen, 10 per cent of the individuals had limitations in 3 of the 4 characteristics, namely, the first, second, and fourth. It is particularly interesting to note that 14 per cent had no evident limitations that would prevent them from stepping into positions of considerably greater responsibility when such positions become available. Some of these men will become impatient at the slowness of their advancement and will seek opportunities elsewhere. They may meet with large success or they may find themselves in a hostile environment which will ruin their morale temporarily or permanently.

It should be noted that figures 3 and 4 refer to the same men and both deal with their faults and limitations. That the results are not the same, is, of course, because in the 2 sets of data these men are viewed from different standpoints. In figure 3 they are considered from the viewpoint of their present occupations and responsibilities, while in figure 4 they are judged on the basis of larger responsibilities and a different type of contact with their associates. The percentages are, therefore, higher in figure 4 than in figure 3 for the same characteristics. Also, a few characteristics that appear in figure 3 are omitted in figure 4, and a few are added that are of little or no importance in considering the data of figure 3.

## Discussion of Results

It is believed that the tables and figures presented will answer some of the questions raised in the first part of this paper. Of course another person making these ratings would obtain somewhat different percentages from those appearing in the figures. It is believed, however, based upon checks by others, that the discrepancies would not be large. The tendency seems to be to rate the "temperamental faults" even higher than given in the graphs.

Of the men released, it is interesting to note that a slightly larger percentage consisted of those hired direct as compared with those obtained through the student training course. Of those who remained through the depression about $^2/_3$ came in through the student course. This is in spite of the fact that many of those who were hired directly for research had special training or qualifications for the particular work in which they were engaged. The number of men originally on the staff was about $^1/_2$ of each kind.

In a research organization it would be thought without analysis, that "mental capacity" and "technical training" would be of paramount importance, the "temperamental traits" being of decidedly secondary value. These analyses indicate quite the opposite. It must be remembered, however, that those lacking in the 2 former traits are, to a large extent, eliminated during their school days and apprentice training. Many students, nevertheless, never should have been released to industry because of their mental limitations or their different interests.

From these analyses then, it would seem desirable in the training and guidance of students, to pay more attention to the "temperamental traits." Scientists and technicians are influenced just about as easily by likes and dislikes and prejudices as any other class of people. No matter how brilliant a man may be he cannot be successful in group activities unless he can obtain coöperation. He must have the respect and liking of his fellow workers. For his greatest success he must be sufficiently aggressive to convince others of the value of his activities and to some extent, at least, he must sell himself to his superiors.

In order to bring out a man's strength and weakness in coöperative activities (most important research and development are now of this kind), it might be desirable for the schools to sponsor thesis and research projects that instead of involving 1 or 2 men for each project might require a group of a dozen or more. Each individual might be rated on the basis of his effectiveness as a member of the group and his group shortcomings pointed out to him.

Finally, it is obvious to those who are brought into close contact with technical school graduates that there still are many who never should have majored in engineering or science. The obvious solution for this difficulty is psychological examinations in the secondary schools and better guidance in the choice of a profession by competent advisers. The technical schools themselves doubtless could be more critical in their entrance requirements and should be more drastic in their eliminations during the first year. As graduation time approaches students undoubtedly could be saved many future disappointments if they received more guidance in the selection of a vocation. A man with the temperamental traits suited to a sales engineer should not be allowed to choose design. A man who is a poor experimenter and a good teacher should be made to realize his points of strength and weakness before he leaves school and should be directed in his future activities accordingly.

Most of the foregoing is obvious, but it cannot be stressed too strongly. This is evident when it is realized how far from ideal present conditions are. Many attempts in the way of vocational guidance are being made for the skilled and unskilled workman, but all too little is being done for the technical school graduate in whom there is a large investment and on whose shoulders more and more of the world's problems are evidently soon to rest. Years are spent in cramming abstract knowledge into the students' heads, but almost no effort is being expended in preparing them to make the best use of it after they leave school.

It is hoped that these analyses will give the young man entering industry, the teachers who have prepared him, and the employers who will use him a more accurate picture of the nature of the strength and weaknesses of these young men. A consideration of the importance of the temperamental traits may lead to greater efficiency and the elimination of much disappointment and perhaps suffering on the part of those who from time to time under present conditions are forced to seek other employment.

# Ratings of Industrial Electronic Tubes

**To serve as a guide in the standardization of ratings of electronic tubes, the principal factors involved in the choice of tube ratings together with the more important terms commonly used, are presented in this paper. High vacuum tubes, gas and vapor filled tubes, and photo-electric tubes are considered separately, and the large number of factors which enter into the ratings of each of these 3 classes of tubes are discussed.**

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THE proper determination and standardization of ratings of electrical apparatus is one of the most important and difficult duties with which an engineer is faced. This is particularly true in the case of electronic devices because of the great variety of applications for a given type of tube. Ratings here must guide the application engineer in obtaining maximum value on the one hand and must serve to determine the responsibility of the manufacturer in the case of inoperative apparatus on the other. The more important terms in use for rating vacuum tubes are described in this paper and the technical conditions governing the choice of tube ratings are presented.

Ratings should always be based primarily upon the *fundamental limitations of tubes* in order that they may be correct under the many conditions encountered in service. It is, therefore, necessary first to determine what elements of a tube may be independently or collectively subjected to damage by improper use and then to establish within what limits each may be operated consistent with the desired life and performance. Thus, in the case of rectifier tubes there are certain ratings based upon the ability of the cathode to provide emission, others upon the ability of the tube to withstand inverse voltage, and still others on the capacity of the tube to dissipate and distribute heat.

## High Vacuum Tubes

Because of the greater simplicity of operation and the smaller number of fundamental limitations of high vacuum tubes, the ratings of this type are discussed first in this paper. Under this classification are considered only those tubes which have been sufficiently exhausted that their characteristics and operation are unaffected by such residual gases as may still be present. In practically all such tubes the principal consideration is the passage of a pure electron stream, either under or without the influence of one or more interposed grids, from a heated cathode to a relatively cold anode. These simple but essential features involve the following inherent limitations.

### *Cathode Ratings*

Most modern high vacuum tubes have thermionic cathodes of tungsten, thoriated tungsten, or oxide coated alloys, each having its own peculiar advantages and limitations. For each, however, the electron emission increases exponentially with increasing temperature, and definite limitations must, therefore, be put on the heating voltage of any tube so as to insure sufficiently high temperature to provide the necessary electron emission and yet prevent too high temperature. The latter would result in early failure due to burn-out in the case of tungsten filaments or loss of emissive material in the case of thoriated tungsten and oxide coated filaments. While any variation from the rated cathode heating voltage is undesirable, a plus or minus 5 per cent variation is generally considered tolerable.

### *Maximum Plate and Grid Currents and Dissipation*

A given cathode thus provides a rather definite maximum electron current which can be drawn safely and economically from it. This obviously introduces a fundamental limitation in any tube and is, therefore, a factor which should have a definite rating. This rating is stated in terms of maximum plate and grid currents.

The use of vacuum tubes in different types of circuits results in tube efficiencies varying over a wide range and the heat developed at the anode varies accordingly. In order to prevent excessive anode temperatures, resulting usually in evolution of occluded gases from overheated parts, it is necessary to establish maximum wattages which can be dissipated safely as heat by the anode. Likewise, the grid or grids have similar limitations and where tubes are operated in such a manner that electron current is drawn to the grid, maximum grid dissipation limits must be observed. Incidentally, the grid dissipation is in general higher than calculated by taking the product of voltage and current, since secondary electrons emitted from the grid diminish the grid ammeter reading proportionally, though do not lessen the grid bombardment. A grid may thus run red hot when the calculated input wattage is zero or even negative.

### *Maximum Plate Voltage*

All tubes have fairly definite anode voltage limitations beyond which short life or even sudden failure

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will occur. The cause of failure may in such cases be an actual glow or arc between electrodes. Often, however, it is loss of emission due to excessive, though invisible, ionization of residual gases and the resulting bombardment of the electrodes.

*High Frequency Ratings and Limitations*

In certain industrial applications, as well as in radio, it is desirable to use vacuum tubes as oscillators or amplifiers at extraordinarily high frequencies—of the order of 10 to 100 million cycles. Under such conditions dielectric losses are developed in the glass and other insulating materials, eddy currents may be set up in metal parts, ionization of residual gases tends to persist, unusually high voltages may develop between adjacent parts and, therefore, ratings which are feasible at ordinary radio frequencies and below cannot apply. It becomes necessary, therefore, to rate such tubes in terms of frequency as well as in terms of voltage, currents, etc.

## Gas and Vapor Filled Tubes

Generally speaking, all of the limitations mentioned above which are characteristic of high vacuum tubes, apply also to gas and vapor filled or ionic tubes. There are, however, a number of additional factors introduced by the presence of gas in the tube, and, since tubes of this class are of primary importance in industrial and power fields, their limitations and ratings are considered in more detail.

*Maximum Average Anode Current*

These tubes all have the common characteristic of being able to carry relatively heavy currents across the evacuated space between electrodes with a comparatively low voltage drop. This is accomplished at present by the use of thermionic cathodes, mercury pools, and cold cathode discharges. With all of these methods a certain voltage drop is set up across the tube. This results in losses which must be limited and it is, therefore, necessary to apply a current rating based upon tube heating. Inasmuch as in these devices the voltage drop is fairly constant for all values of current, this rating is given in terms of average current rather than root mean square current as in the case of a conductor. It is realized that even this is an approximation in the case of highly peaked wave forms. Of course, the design of tube conductors, such as leads, must be based upon the root mean square current and due to the very peaked wave forms which are encountered, this root mean square value is often many times the average.

*Maximum Instantaneous Anode Current*

In the case of thermionic cathodes, the available electron emission represents a limit on the maximum instantaneous current which may be carried across the space without harm to the tube. In polyphase circuits the instantaneous current requirement is often 6, and sometimes as much as 12, times the average current per tube. Thermionic tubes usually have an instantaneous rating of not over 6 times the average current rating, which is sufficient in most cases.

However, since neither the average nor the instantaneous ratings may be exceeded, it is obvious that in some circuits the instantaneous current rating will be the limiting factor in attempting to get more power out of the tube while in other circuits the average current maximum will be reached first.

In the case of pool and cold cathodes the instantaneous current, from the standpoint of the cathode is more or less limitless. Thus, some pool tubes with an average rating of 10 amp can carry several thousand amperes instantaneously.

*Maximum Anode Surge Current*

In the design of electrical equipment using tubes, it has been found necessary in many cases to limit the abnormal current flow under short-circuit conditions, as it is not always economical to design tubes to withstand without harm extremely high transient currents. The maximum permissible transient current is sometimes termed the surge current rating and is the value of transient current to which a tube may be subjected occasionally without causing immediate failure or affecting the life unduly. As an example, this current sometimes determines the value of reactance desirable in the transformer windings of a rectifier.

*Maximum Time of Averaging Anode Current or Load Time Constant*

Electromagnetic devices usually have a high thermal capacity. Thus, a motor may stand severe overload for a period of perhaps half an hour before attaining dangerous temperatures. Because of the necessity of keeping the internal parts light in order to reduce the occluded gas content, tubes have comparatively low thermal capacity and, therefore, acquire thermal equilibrium in a few seconds or at most a few minutes. In the case of slowly repeating duty cycles it can be seen that some limit or integration period must be placed on the time over which the current is averaged.

For example, consider a tube which has an instantaneous current rating of 30 amp and an average current rating of 5 amp. Obviously it would not be safe to apply a load of 30 amp for one hour during every 6 hr, though this would allow only an average current equal to the average current rating of 5 amp. In other words, the period over which the current is averaged must be short enough that the highest temperature reached will not be in excess of that obtained if a steady current equal to the average current rating is kept on continuously. In the case of a tube having a 5-amp average current rating, this integration period, or load time constant, would probably be of the order of 30 sec. The maximum period, therefore, that the highest permissible current of 30 amp could be passed through the tube would be 5 sec out of any 30-sec period, since any greater value would cause the average current rating to be exceeded. In practice, a half-wave tube handles only half of each active cycle and the consideration is further complicated by wave forms. Thus, assuming substantially square wave form and with half wave rectification, 600 half cycles of current having a maximum value of 30 amp could be carried over a 10-sec

period, the current actually flowing for half this time.

### *Maximum Peak or Crest Inverse Voltage*

Turning now to the voltage ratings of gas and vapor filled tubes, a great variety of circuits must be considered and it is necessary to get back to the tube fundamentals. At one time rectifier tubes were rated in terms of their d-c outputs, but this is meaningless except for one ratio of a-c voltage to d-c voltage. The fundamental is the ability of the tube to withstand instantaneous voltages. Thus, there is necessitated the maximum peak or crest inverse voltage rating and, in the case of tubes with grid control, the maximum peak or crest forward voltage rating as well. In obtaining the peak or crest voltage in any circuit it is necessary to take into account not only the type of circuit but also the frequency, the wave forms, and the presence of surges or transients which may increase the voltage to which the tube is subjected. In the case of complicated conditions it is often necessary actually to test for this voltage by means of a cathode ray oscillograph or a spark gap.

### *Cathode Ratings*

For purposes of interchangeability and to permit of parallel operation, practically all thermionic cathodes are designed for constant voltage heating supply. The maximum and minimum currents at this voltage are often listed for calculation of efficiencies and design of heating transformers. Emission and life vary greatly with variations in filament temperature and hence with filament voltage. Thus, an overvoltage shortens life somewhat and undervoltage reduces the emission of the cathode, which may result in a change in tube characteristics or even immediate failure. It is, therefore, desirable that the heating voltage be kept as constant as possible and at least within plus or minus 5 per cent of normal, particularly where the voltage fluctuations are slow. It is always recommended, however, that the voltage be too high rather than too low, as overvoltage seldom results in rapid failure.

### *Cathode Heating Time*

It requires a certain length of time to bring thermionic cathodes up to temperature. Attempts to draw current prior to the time that operating temperature is reached often results in harm to the tube. Simple, unshielded filaments are much quicker heating than enclosed filaments or cathodes. Thus the heating time varies from a few seconds, in the case of the former, to as high as 30 min, in the case of the latter. The slower heating cathodes are more efficient; therefore, there is always a compromise in the design of cathodes between efficiency and heating time. It is necessary to know the heating time of the cathode and provide either manually or with relays for the delay in application of anode voltage.

### *Tube Heating Time*

In the case of mercury vapor tubes it is necessary to raise the mercury temperature to a point that will produce a vapor pressure sufficient to carry the current properly. The coolest point of the tube determines this pressure. Thus, a filamentary cathode mercury tube might have a cathode heating time of 5 sec but a tube heating time of 5 min. Tube heating time varies with the thermal capacity, ventilation, cathode watts, external heating, and with the type of circuit. Likewise, the characteristics of mercury vapor tubes vary with tube temperature and in the case of critical circuits or wide temperature variations it is often necessary to maintain the temperature constant by means of thermostatic devices. In rating mercury tubes it is, therefore, necessary to establish temperature limits. These were first given in terms of the ambient temperature but confusion resulted due to the fact that the relation between ambient and condensed mercury temperature, i. e., minimum bulb temperature is not constant. It varies greatly with the ventilation and with load. Temperature limits of tubes are now being given more and more in terms of condensed mercury temperature, and it is left to the application engineer to relate this properly with ambient.

The temperature characteristics of pool cathode tubes are substantially equivalent to thermionic cathode tubes except that the cathode requires no heating time.

On the other hand, inert gas filled tubes have characteristics substantially independent of tube temperature and are ready for operation as soon as the cathode has attained its normal temperature.

### *Tube Voltage Drop*

It is necessary to establish the voltage drop across tubes in order to serve as a basis of efficiency calculation and for transformer design. In cold cathode gas discharge tubes this is rather high, often being in the neighborhood of 100 volts, while in the case of hot cathode tubes it ranges from 5 to 30 volts. Pool tubes have drops of from 10 to 30 volts. Drop, in the case of mercury tubes, is a function of temperature, and it is, therefore, possible and sometimes desirable to operate a tube at a high temperature for the purpose of reducing the drop and consequently the losses. Drop also varies slightly with current and in calculating efficiencies this must be taken into account. Thus, a 6-phase rectifier supplying 600 amp demands approximately 600 amp from each tube in turn. The drop used here should be that for 600 amp rather than for the average value of 100 amp.

### *Starting or Control Characteristics*

In the case of ionic tubes having grids, the control characteristics are of utmost importance. In this type of tube there is a critical grid voltage for each anode voltage at which current starts to flow. This may be either positive or negative. (It should be remembered that with this type of control the stoppage of current is usually not accomplished by means of the grid.) Ratings usually include the critical grid voltage at a low anode voltage, such as 100 volts, and at the maximum rated voltage of the tube. In the case of negative control tubes the zero grid starting voltage is also usually given.

*Grid Current Ratings*

Another fundamental characteristic and limitation of ionic tubes is based upon current drawn by the grid. Grid current limits fall under 3 general classes: (1) Grid current before starting; (2) minimum grid current after starting; and (3) maximum rated grid current after starting. The first 2 are more properly characteristics than ratings and in general the lower values will be associated with superior tubes. These characteristics are best illustrated by a family of curves showing the variation with voltage, tube temperature, anode current, and circuit conditions.

The maximum rated grid current after starting, like the anode ratings, is expressed in terms of the average current, based upon grid heating, and in the case of hot cathode tubes, in terms of the instantaneous current based upon the added current requirement from the cathode.

*Deionization Time*

In many types of applications of ionic triodes, particularly in inverter circuits, the time required for the grid to regain control after current interruption is of fundamental importance. This interval during which a grid voltage, more negative than the critical value, fails to block off the anode current is termed the "deionization time." This is ordinarily of the order of microseconds, and is a function of tube geometry, condensed mercury temperature, plate and grid currents, plate and grid voltages, and of regulation of the grid circuit. It is, therefore, rather meaningless to specify a given value for the deionization time of any tube without limiting the conditions under which it applies. A complete description of this characteristic can only be given by means of a family of deionization time curves.

## Photo-Electric Tubes

While photo-electric tubes have found rather large and varied fields of application, their fundamental limitations are relatively very few and consequently the matter of ratings is correspondingly simpler than in the case of other industrial tubes.

*Maximum Anode Voltage and Current Ratings*

Photo-electric tubes are essentially of 2 types—high vacuum and gas filled. In the high vacuum type there is a limit to the maximum anode voltage which may be applied without the development of undue leakage over the insulation between electrodes or breakdown of residual gases which may be in the tube. There is also a limit to the maximum anode current. Practically, however, these limitations are far beyond any ordinary requirement.

In many photo-electric tubes, an inert gas is used and the sensitivity may thereby be increased several fold due to gas ionization. Such tubes have a quite different anode voltage rating from the high vacuum type. This is because a glow discharge will take place between electrodes at about 100 volts with gas pressures which are otherwise optimum, and this in turn results in rapid deterioration of sensitivity. It is necessary, therefore, to establish a rather low but definite upper limit, ordinarily not over 100 volts, to the anode voltage which may be applied to the gas photo-electric tube. Since the glow voltage is also a function of intensity of illumination, it is also required that a high resistance be used in series with the voltage supply, thus dropping the applied anode voltage as the photo-electric current increases.

*Maximum Ambient Temperature*

In the more sensitive type of photo-electric tubes, operation at relatively high temperatures results, first, in a loss of photo-electric sensitivity and second, in the beginning of thermionic emission from the cathode. This latter effect makes a part of the total current independent of illumination and is, therefore, objectionable. It has been found necessary, therefore, to limit the maximum temperature to the order of 60 deg C.

*Sensitivity*

The sensitivity of photo-electric tubes, while more of a characteristic than a rating, is expressed in terms of microamperes short-circuit current per lumen of incident radiant flux. The luminous tungsten sensitivity is the sensitivity with the tube subjected to a tungsten filament at specified color temperature. A standardized temperature for the filament of the test lamp is 2,870 deg absolute.

## Standardization of the Different Types of Tubes

No one doubts the value of and necessity for standardization of ratings of electrical equipment. It is particularly important in the case of tubes as they are usually replaceable items of equipment. Obviously, lack of standardization of base and outline dimensions, voltage and current levels and general electrical characteristics must lead to a great number of unnecessary tube types which would, of course, be detrimental to the art.

In considering different sizes of tubes it is suggested that all ratings, so far as practicable, and particularly average current ratings, should fit into a "preferred number" system. (See "Standardization and Profits Aided by Preferred Numbers," R. E. Hellmund. *Elec. World*, v. 104, 1934, p. 208–11.) Preferred numbers are based upon a geometric progression and have been found valuable in practically all types of standardization. It is, of course, necessary to divide the tube field into classes, such as high voltage control tubes, low voltage control tubes, high voltage rectifiers, low voltage rectifiers, each group being further divided into both the high vacuum and gas filled types, but within a given classification the use of the preferred number system will minimize the number of improperly spaced types of tubes.

The actual standardization of tube ratings by technical committees has only just started and it is hoped that this paper may serve as a guide for this work.

# Resistance and Reactance of 3-Conductor Cables

**The resistance and reactance of 3-conductor cables under balanced 3-phase loads have been studied in a series of tests in different laboratories, and the results are presented in this paper. Values of these constants are given for different types and sizes of 3-conductor cable, and the effects on the constants of several different factors are presented.**

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EXPERIMENTAL data have been lacking covering the combined action of skin effect, proximity effect, and sheath losses in the determination of the effective a-c resistance of multiple conductor cables. With the advent of multiple conductor cables of the larger conductor sizes, the need for information concerning the probable losses in these cables became imperative.

Early in 1930, W. H. Cole of the Edison Electric Illuminating Company of Boston (Mass.) called attention to certain difficulties which had been experienced in the parallel operation of belted and shielded types of 3-conductor cables. As a consequence of these troubles measurements were made of the resistance, reactance, and impedance of 2 installed lengths of cable each about 57,000 ft long. The results of these measurements indicated values considerably in excess of those normally assumed in line calculations.

These conditions were called to the attention of the manufacturers involved and of Electrical Testing Laboratories with the immediate result that hurried laboratory measurements were made on various lengths of cable available. The results, in general, confirmed Mr. Cole's findings, though the values of effective resistance obtained were somewhat lower than those reported by Mr. Cole.

An investigation was then undertaken by Electrical Testing Laboratories on behalf of the high tension cable committee of the Association of Edison Illuminating Companies, and the Insulated Power Cable Engineers' Association on behalf of the cable manufacturers. The work reported herein is a result of the coöperative efforts of these 2 groups.

The investigation included the determination of the constants of belted and shielded types of cables with 167,000 to 1,000,000-cir-mil conductors and with several different thicknesses of insulation.

A description of one of the test methods used and the results of the various interlaboratory and field checks made to assure reliability of these results are given in the appendixes.

## Results of Tests and Investigations—
### 1. Constants of 3-Conductor Cables

The original schedule of testing contemplated making practically all measurements on dry or unimpregnated cable because most of the test specimens had to be manufactured specially for this investigation and it was felt that considerable economy could be effected if the work could be done on dry cable. Accordingly, the first group of samples supplied were unimpregnated but were otherwise standard commercial cable.

In the course of the determination of the magnitude of proximity effects between conductors, a test was made on the stripped cable and then the conductors were spread 17 in. apart on the apexes of an equilateral triangle and a second test made. A marked decrease in effective resistance was noted when the conductors were separated 17 in. in the manner indicated, at which distance all proximity effects should be negligible. However, when a piece of impregnated cable was tested in this manner, little or no change was obtained in the effective resistance of the conductors.

This indication of an apparent effect due to impregnation was first checked by crudely impregnating the conductors of a piece of dry cable and repeating the tests on the impregnated cable. The result tended to confirm the findings as to the effects of impregnation. As a final check, 2 15-ft pieces were cut from one of the samples of dry cable, one rereturned to the factory for regular factory impregnation and the second held for tests in the dry condition. The results of these tests were definite in their indication that all measurements should be made on cable which has been dried and impregnated in the usual manner.

When this conclusion was reached, 20-ft pieces were cut from all of the unimpregnated samples and returned to the various manufacturers for factory drying and impregnation. The bulk of the results reported herein are, therefore, those obtained in tests of the impregnated cable. As such they are believed to be representative of the characteristics of the normal run of cables as now manufactured.

The cables tested may be divided into 2 general classifications according to the conductor shape,

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* On behalf of a committee of the Insulated Power Cable Engineers' Association, composed of: R. J. Wiseman, *Chairman*, W. A. Del Mar, G. B. Shanklin, and D. M. Simmons.

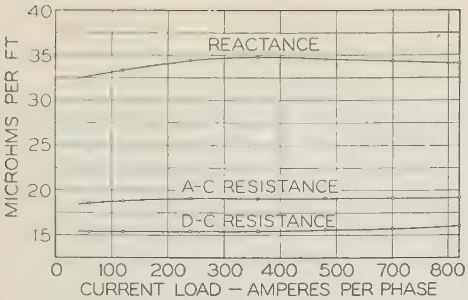



**Fig. 1. Typical curves of a-c resistance and reactance of shielded cable with magnetic binder tape**

Description of cable: 3 × 700,000 - cir-mil round conductor 220 mils, impregnated paper insulation; 141 mils, lead sheath

i. e., round and sector. Under each of these classifications there were cables of 3 different types of construction, namely, the belted construction, the shielded cable with the steel binder tape (magnetic) and the shielded cable with each of several nonmagnetic binder tapes. (A description of these different types of construction is given in a later section "5. Parallel Operation of 3-Conductor Cables" of this paper.)

Certain types of results were soon recognized as typical of the various types of cable under test. Table I and Fig. 1 show such typical results. It was noted that the resistance and reactance versus current characteristics were practically horizontal straight lines for all *nonmagnetic* cables. The only deviation from the straight line appeared to be due to heating of the cable as it was loaded. However, the introduction of a steel binder tape changes the shape of these curves to those typical of circuits containing magnetic materials. This means that for complete information on the several types of cable it is necessary to show the complete range of data at various currents. In normal use, however, the values of most interest are those corresponding to full load operating conditions. In the preparation of summary tables the cable constants at a single current load have, therefore, been given, approximately, the maximum operating load. Furthermore, since it is in most cases more convenient to deal with the effective resistance as a ratio to the d-c resistance, only such ratios have been given.

Table II is a summary of all the available results of measurements made on the various sizes and types of cables. This table includes measurements made in all the various laboratories. In Fig. 2 is a graphic presentation of the various data on effective resistance, while Fig. 3 presents the results of the reactance measurements. In preparing these charts the results for the various types and conditions have been identified though only limit curves have been drawn in most cases.

In connection with certain check measurements made in coöperation with one of the cable manufacturers, attention was called to an unexplained condition noted in their tests, namely, that the effective resistance apparently differed with the phase rotation of the current. Further investigation confirmed this effect and appeared to show that it was inherent in the cable and was independent of the test or supply circuits. It was found that where the current phase rotation agreed with the rotation of the conductors due to lay (viewed from the supply end) the effective resistance was approximately one per cent higher than where the current phase rotation was opposite to the rotation of the conductors. However, theoretical considerations seem to indicate that losses cannot be dependent upon the direction of energy flow and thus an explanation of the effect of direction of phase rotation would require further investigation. The data reported herein are average values taken from direct and reversed measurements at each current value.

## 2. The Effect of Frequency on Cable Characteristics

In connection with the early work on the dry cables a study was made of the effect of frequency on the cable characteristics. In this study the cable constants were determined by the 2-wattmeter method at a given balanced 3-phase current load over a range of frequencies from about 20 cycles per second to 62.5 cycles per second. These measurements indicated a straight line variation with frequency for both the effective resistance and reactance, the effective resistance increasing from a value equal to the d-c resistance at zero frequency and the

**Table I—Typical Results on Shielded Cable, Magnetic Binder Tape, With and Without Sheath**

Reactance and A-C and D-C Resistance in Ohms per 1,000-ft of Conductor

| | Three-Phase Current Load—Amperes per Phase | | | | | | | Surface Temp. |
|---|---|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | 600 | 700 | |
| **Cable Complete** | | | | | | | | |
| Reactance | 0.0331 | 0.0342 | 0.0348 | 0.0348 | 0.0346 | 0.0344 | 0.0341 | Start, |
| A-c resistance | 0.0187 | 0.0191 | 0.0191 | 0.0190 | 0.0190 | 0.0190 | 0.0192 | 21.7C; |
| D-c resistance | 0.0153 | 0.0153 | 0.0154 | 0.0155 | 0.0156 | 0.0158 | 0.0160 | Finish, |
| A-c res./d-c res. | 1.22 | 1.24 | 1.24 | 1.23 | 1.22 | 1.21 | 1.20 | 28.0 C |
| **Minus Lead Sheath** | | | | | | | | |
| Reactance | 0.0334 | 0.0344 | 0.0349 | 0.0349 | 0.0347 | 0.0344 | 0.0342 | Start, |
| A-c resistance | 0.0179 | 0.0185 | 0.0186 | 0.0185 | 0.0183 | 0.0183 | 0.0183 | 26.6C; |
| D-c resistance | 0.0156 | 0.0156 | 0.0156 | 0.0157 | 0.0158 | 0.0159 | 0.0161 | Finish, |
| A-c res./d-c res. | 1.14 | 1.18 | 1.19 | 1.18 | 1.16 | 1.15 | 1.14 | 30.0 C |
| **Minus Lead Sheath and Steel Binder Tape** | | | | | | | | |
| Reactance | 0.0314 | 0.0314 | 0.0314 | 0.0314 | 0.0314 | 0.0314 | 0.0314 | Start, |
| A-c resistance | 0.0169 | 0.0169 | 0.0169 | 0.0169 | 0.0170 | 0.0172 | 0.0173 | 24.1C; |
| D-c resistance | 0.0155 | 0.0155 | 0.0156 | 0.0156 | 0.0157 | 0.0158 | 0.0160 | Finish, |
| A-c res./d-c res. | 1.09 | 1.09 | 1.09 | 1.09 | 1.09 | 1.08 | 1.08 | 27.0 C |

Description of Cable—3 × 700,000 cir mils, round conductor; shielded, steel binder tape; impregnated paper, 220 mils; lead sheath, 141 mils

reactance being directly proportional to frequency. The results of a typical set of tests are shown in Fig. 4.

## 3. Proximity Effects in Adjacent Cables

The values of a-c resistance indicated by laboratory tests were in the most cases lower than the values shown by the early field tests on long lengths of installed cable. It was suggested that possibly one reason why the field tests showed the higher values was that there were induced currents set up in adjacent cables in the duct banks. Such proximity effects would, of course, be reflected as higher losses in the cable under test.

In order to ascertain the probability of such an explanation a series of tests was run on samples of 3-conductor 700,000-cir-mil cable, each about 20 ft in length. A given sample was first placed in position and tested in the normal manner with no metallic bodies nearby. Then, without disturbing the cable under test, other pieces of similar cable were laid parallel to the test sample with 6 in. between centers. The cables laid parallel to the test sample were, of course, insulated from the test sample in order to prevent circulating currents which might exist due to possible unbalance in the short length of cable under test.

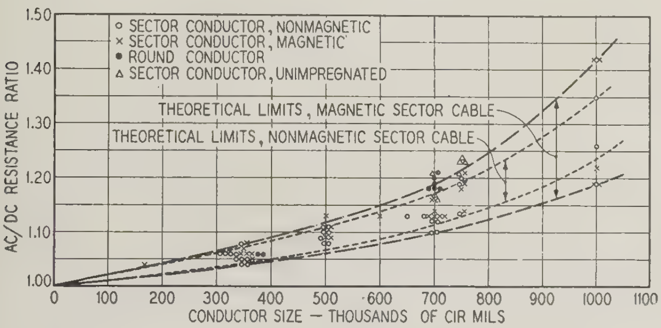



**Fig. 2. 60-cycle effective resistance of 3-conductor cable at 30 deg C, expressed as a ratio to the d-c resistance**

The results of these tests are shown in Table III and appear to indicate that under normal duct spacing of 6 in. between centers the proximity effects between cables are negligible. However, when the distance between cables is decreased to 3.5 in. an appreciable influence begins to be evident.

## 4. Mechanical Forces Between Conductors Under Short-Circuit Conditions

At the time of this investigation of cable characteristics, one of the laboratories, as a part of this investigation, studied the mechanical stresses developed in the binder tape of 3-conductor shielded cable under short-circuit conditions and their relation to the tensile properties of the tapes being used. This problem has been approached both from the theoretical and from the experimental side with much the same result.

A study of the field conditions surrounding the 3 conductors has indicated that under a phase to phase short circuit in which the current reaches a value of 20,000 amp the force to be resisted amounts to about 250 lb per foot of cable ($3 \times 350{,}000$ cir mils, 220 mils insulation on each conductor). Assuming this force to be resisted by a binder tape one inch between turns, the stress in the tape would be of the order of 3,500 lb per square inch. The force exerted will vary as about the square of the current so that even under short-circuit currents of twice this magnitude the forces encountered would be effectively restrained by a tape binder of any of the materials now being used. In fact, the lead sheath alone would probably provide sufficient strength to resist these forces.

In order to check the above conclusions a series of tests was run in which various cable samples were submitted to momentary overloads of approximately 12,000 amp. This current was caused to flow through one conductor in one direction and back again in the opposite direction through the other 2 in parallel. Tests were made on each of 3 specimens of $3 \times 350{,}000$-cir-mil shielded cable—one with a steel binder tape, one with a wire stitched cloth binder tape and one with a butt-wound 7-mil paper binder tape. All were provided with a 125-mil lead sheath.

Each sample was subjected 3 times to the 12,000-amp momentary load. After each test the sample was examined carefully and measured for signs of movement. In no case could any perceptible movement of the conductors be detected.

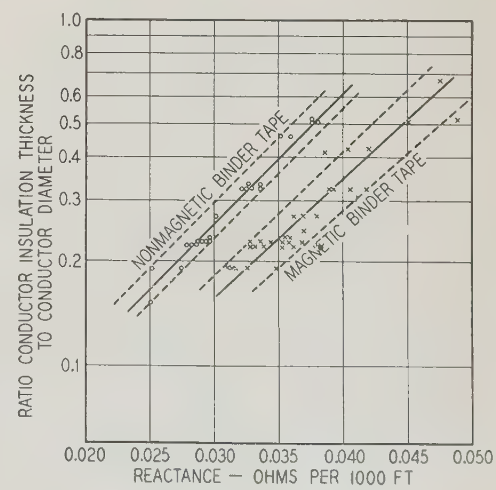
The lead sheath was then removed from each sample and the binder tape tied at each end to prevent unwrapping. Each sample was again subjected to 3 12,000-amp tests and again there was no preceptible movement of the conductors.

## 5. Parallel Operation of 3-Conductor Cables

Since difficulties in the parallel operation of 3-conductor cables were the underlying cause for this investigation, it appears proper to treat here of those inherent conditions which will always be encountered when such cables are installed for parallel operation. Belted cable is the oldest type of 3-conductor cable

**Fig. 3. 60-cycle reactance to neutral of 3-conductor sector cable**

Conductor diameter of sector cable taken as that of round conductor of same cross section



## Table II—A-C Resistance and Reactance of 3-Conductor Cables Under Balanced 3-Phase Load

Values Taken at an Average Conductor Temperature of 30 Deg C

| Cable No. | Type of Construction | Shape of Conds. | Thick. of Insulation, mils | Thick. of Lead sheath, mils | Effective Resist., Ratio to D-C Resist. | Reactance[1] |
|---|---|---|---|---|---|---|
| | **3 × 167,000-cir-mil (3/0 A.w.g.) cables, 200-amp load** | | | | | |
| 1 | Shielded-steel binder | Sector | 313 | .125 | 1.04 | 0.0475 |
| | **3 × 350,000-cir-mil cables, 300-amp load** | | | | | |
| 2 | Belted | Round | 440 × 267 | .125 | 1.06 | 0.0336 |
| 3 | Belted | Sector | 562 × 500 | .141 | 1.04 | 0.0430 |
| 4 | Belted | Sector | 440 × 344 | .125 | 1.05 | 0.0328 |
| 5 | Shielded steel binder | Round | 220 | .125 | 1.08 | 0.0390 |
| 6 | Shielded steel binder | Sector | 350 | .141 | 1.05 | 0.0488 |
| 7 | " " " | Sector | 220 | .125 | 1.06 | 0.0418 |
| 8 | " " " | Sector | 345 | .125 | 1.08 | 0.0447 |
| 9 | " " " | Sector | 345 | .125 | 1.07 | |
| 10 | " " " | Sector | 220 | .125 | 1.06 | 0.0406 |
| 11 | " " " | Sector | 345 | .125 | 1.14 | |
| 12 | " " " | Sector | 220 | .125 | 1.06[4] | 0.0391 |
| 13 | Shielded copper binder | Round | 220 | .125 | 1.06 | 0.0337 |
| 14 | " " " | Sector | 350 | .141 | 1.06 | |
| 15 | " " " | Sector | 281 | .125 | 1.06 | |
| 16 | " " " | Sector | 345 | .125 | 1.06 | 0.0380 |
| 17 | " " " | Sector | 220 | .125 | 1.04[4] | 0.0321 |
| 18 | Shielded bronze binder | Sector | 345 | .125 | 1.06 | 0.0377 |
| 19 | Shielded cloth binder | Sector | 220 | .125 | 1.05 | 0.0323 |
| 20 | " " " | Sector | 345 | .125 | 1.06 | 0.0376 |
| 21 | Shielded paper binder | Sector | 220 | .125 | 1.05 | 0.0326 |
| | **3 × 500,000-cir-mil cables, 400-amp load** | | | | | |
| 22 | Shielded steel binder | Sector | 345 | .125 | 1.11 | 0.0404 |
| 23 | " " " | Sector | 340 | .125 | 1.13 | |
| 24 | " " " | Sector | 220 | .141 | 1.09 | 0.0380 |
| 25 | " " " | Sector | 345 | .125 | 1.11 | 0.0420 |
| 26 | " " " | Sector | 220 | .141 | 1.16 | 0.0369 |
| 27 | " " " | Sector | 345 | .125 | 1.16 | |
| 28 | " " " | Sector | 375 | .125 | 1.17 | |
| 29 | " " " | Sector | 375 | .125 | 1.11 | |
| 30 | " " " | Sector | 220 | .125 | 1.09[4] | 0.0362 |
| 31 | Shielded paper binder | Sector | 375 | .125 | 1.09 | |
| 32 | " " " | Sector | 375 | .125 | 1.08 | |
| 33 | " " " | Sector | 375 | .125 | 1.10 | 0.0351 |
| 34 | " " " | Sector | 375 | .125 | 1.10 | 0.0359 |
| 35 | " " " | Sector | 220 | .125 | 1.075[4] | 0.0302 |
| | **3 × 600,000-cir-mil cables, 500-amp load** | | | | | |
| 36 | Shielded steel binder | Sector | 220 | .125 | 1.13 | 0.0370 |
| 37 | " " " | Sector | 220 | .125 | 1.27 | |
| | **3 × 650,000-cir-mil cables, 500-amp load** | | | | | |
| 38 | Belted | Sector | 281 × 234 | .125 | 1.13 | 0.0251 |
| | **3 × 700,000-cir-mil cables, 600-amp load** | | | | | |
| 39 | Belted | Round | 440 × 267 | .141 | 1.18[2] | 0.0318 |
| 40 | " | Round | 440 × 267 | .141 | 1.18 | 0.0312 |
| 41 | " | Sector | 440 × 344 | .125 | 1.16[2] | 0.0296 |
| 42 | " | Sector | 440 × 344 | .125 | 1.12 | 0.0290 |
| 43 | Shielded steel binder | Round | 220 | .141 | 1.18[2] | 0.0353 |
| 44 | " " " | Round | 220 | .141 | 1.21 | 0.0344 |
| 45 | " " " | Sector | 220 | .141 | 1.16 | 0.0337 |
| 46 | " " " | Sector | 220 | .125 | 1.21[2] | 0.0358 |
| 47 | " " " | Sector | 220 | .125 | 1.13 | 0.0357 |
| 48 | " " " | Sector | 220 | .141 | 1.13 | 0.0354 |
| 49 | " " " | Sector | 220 | .125 | 1.13 | 0.0356 |
| 50 | " " " | Sector | 220 | .125 | 1.13 | |
| 51 | " " " | Sector | 220 | .141 | 1.14 | 0.0369 |
| 52 | Shielded copper binder | Round | 220 | .141 | 1.20 | 0.0309 |
| 53 | " " " | Round | 220 | .141 | 1.19[2] | 0.0313 |
| 54 | " " " | Sector | 220 | .125 | 1.10 | |
| 55 | " " " | Sector | 220 | .125 | 1.10 | |
| 56 | Shielded brass binder | Sector | 220 | .125 | 1.12 | 0.0289 |
| 57 | Shielded paper binder | Sector | 220 | .125 | 1.17[2] | 0.0297 |
| 58 | " " " | Sector | 220 | .125 | 1.13 | 0.0293 |
| | **3 × 750,000-cir-mil cables, 600-amp load** | | | | | |
| 59 | Shielded steel binder | Sector | 220 | .125 | 1.23[2] | 0.0332 |
| 60 | " " " | Sector | 220 | .125 | 1.21 | 0.0328 |
| 61 | " " " | Sector | 219 | .125 | 1.24[2] | 0.0329 |
| 62 | " " " | Sector | 219 | .125 | 1.19 | 0.0361 |
| 63 | " " " | Sector | 219 | .125 | 1.18 | |
| 64 | " " " | Sector | 220 | .125 | 1.14[4] | 0.0338 |
| 65 | Shielded nicaloi binder | Sector | 219 | .125 | 1.20 | |
| 66 | Shielded copper binder | Sector | 220 | .125 | 1.23[2] | 0.0282 |
| 67 | " " " | Sector | 219 | .125 | 1.21[2] | 0.0280 |
| 68 | " " " | Sector | 219 | .125 | 1.19 | |
| 69 | " " " | Sector | 220 | .125 | 1.135[4] | 0.0287 |
| | **3 × 1,000,000-cir-mil cables, 750-amp load** | | | | | |
| 70 | Shielded steel binder | Sector | 220 | .157 | 1.19[4] | 0.0314 |
| 71 | " " " | Sector | 220 | .157 | 1.42 | 0.0314 |
| 72 | " " " | Sector | 219 | .156 | 1.22[4] | 0.0310 |
| 73 | " " " | Sector | 219 | .156 | 1.42 | 0.0327 |
| 74 | " " " | Sector | 219 | .156 | 1.19[3] | 0.0338 |
| 75 | Shielded everdur binder | Sector | 219 | .156 | 1.35 | 0.0274 |
| 76 | " " " | Sector | 219 | .156 | 1.26[3] | 0.0253 |

1. For numbered references see adjacent column.

and consists of 3 conductors, each insulated, cabled together and wrapped with a belt of additional insulation. This structure is then enclosed in a covering or sheath, which in the case of impregnated paper insulated cable is usually of lead. Due to the nature of this structure, 3 insulated conductors within a sheath, the electrostatic field is quite complicated. Similarly, the geometry of the thermal field is not simple; however, the heat losses from the conductors and the insulation must pass through the body of the insulation to the sheath.

On the other hand, the shielded cable, which consists of 3 insulated conductors each covered with a copper shield, cabled together, bound up with a metal tape and finally sheathed, has a relatively simple field conformation. The copper shields serve, first, to give a configuration to the electrostatic field which is essentially that between concentric cylinders (i. e., radial) and, second, to aid in conducting heat losses from the body of the cable to the sheath. At the same time (and in consequence of the foregoing) the thickness of insulation between conductors and sheath is usually somewhat less than in the belted type of cable. This increased ability to dissipate the internal heat losses makes it possible to assign a higher rated current-carrying capacity and a higher maximum permissible operating temperature to a shielded cable of a given size than to a belted cable of the same conductor size built for operation at the same system voltage.

The measurements made in this investigation show that shielded cable has an inherently greater impedance than belted cable. When the copper ground shields are built into a cable the thickness of insulation on each conductor is necessarily somewhat greater than in the belted type of construction. This means a greater spacing between conductors and consequently an increased inductive reactance. In cases where the binder tape is nonmagnetic this increased reactance causes an increase in the impedance of the order of 2 to 4 per cent above that of the corresponding belted cable. However, when a steel binder is used the resulting impedance is from 10 to 20 per cent above that for the belted cable.

When cables are operated in parallel the load will be divided in such manner as to cause the total voltage drop in each cable to be the same. For the most economical operation, each cable should take a share of the load which is in the same proportion to its rated current-carrying capacity, especially as the full rated load condition is approached. Cables for parallel operation should be so designed as to satisfy this condition as far as possible.

The curves in Fig. 5 illustrate how the voltage drop at rated current for 15-kv cables of various conductor sizes differs for different constructions. The increase in the drop in the shielded *nonmagnetic* type above the belted type is due principally to the inherently higher current capacity for a given copper temperature. The still greater increase in the shielded *magnetic* type is due to the increased inductive reactance.

1. Reactance in ohms per 1,000 ft at 60 cycles, to neutral.
2. Dry cable, i. e., cable which had not been impregnated.
3. Special cable constructed with enameled strands.
4. All strands laid in same direction; each layer crushed.

These curves also show which particular cables as to construction and size will operate economically (i. e., carry their proper share of the load) in parallel with an existing cable. For example, suppose it is proposed to install a cable in parallel with an existing 350,000-cir-mil 15-kv cable of the shielded type with magnetic binder. It is shown in Fig. 5 that the voltage drop to neutral per 1,000 ft of this cable is 15 volts when carrying rated load. If the new cable is to be of the same length, then it is evident that the corresponding drop in it when carrying its rated load must also be 15 volts per 1,000 ft in order to have proper division of the total load between the 2 cables. Reference to Fig. 5 shows that the following cables fulfill this requirement:

145,000 cir mil (approximately 2/0 A.w.g.), belted
225,000 cir mil (approximately 4/0 A.w.g.), shielded, nonmagnetic
350,000 cir mil, shielded magnetic
535,000 cir mil (approximately 500,000), shielded, magnetic

Thus there are 4 cables which will give just the same drop as the original cable with proper division of the load. However, for all practical purposes any size of shielded, magnetic binder cable from say 300,000 to 600,000 or 700,000-cir-mil cable could be used. But if it is desired that the new cable be of the shielded type with nonmagnetic binder, then for any size materially larger than 225,000 cir mil it would be necessary to install a reactor in series with the new cable to get a proper division of the load. Similarly, still more reactance would be required with a belted cable materially larger than 145,000 cir mils.

On the other hand if the existing cable is of the belted type and larger than about 200,000 cir mils, a reactor must be added to it if proper division of load is to be had with a parallel cable of any other type.

These considerations suggest that:

*a.* Since magnetic forms of binder have been found unnecessary for strength purposes, only cables which do not employ magnetic materials be installed in new installations except, of course, where there are special conditions which justify or require the use of magnetic material.

*b.* Where a new cable is to be installed in parallel with an existing cable and one of the same conductor size will provide the desired additional capacity, it be of the same type as the existing cable.

*c.* Where a new cable for installation in parallel with an existing cable is to be of a different conductor size or construction, a study of the conditions along the lines indicated above is necessary to make the best selection.

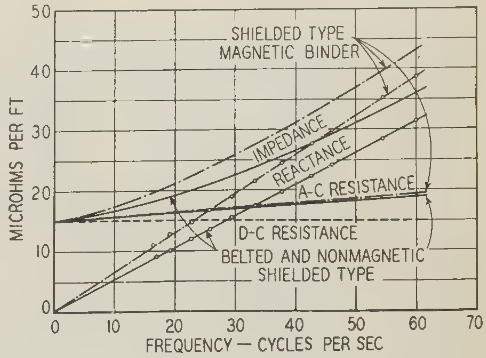



**Fig. 4. Variation of a-c resistance, reactance, and impedance with frequency, for 3 - conductor 700,000 - cir - mil dry cable**

## 6. Study of Component Losses

In the majority of cases the component losses were determined during the laboratory measurements by first determining the total loss of the complete cable sample, then repeating these measurements in order after removing the sheath, metallic binding tape (if any) and, in some cases, finally separating the conductors. Space does not allow detail presentation of these data but representative results will be discussed briefly and compared with theoretical calculations.

Cable without magnetic binder will first be considered. It is possible in these cases to make direct

**Table III—A Study of Proximity Effects Between Cables; A-C to D-C Resistance Ratio**

| Condition | Surface Temp C at Start of Run | Ratio $R_{a-c}/R_{d-c}$ — Three-Phase Current Load; Amperes per Phase: 60 | 120 | 240 | 360 | 480 | 600 | 720 | Surface Temp C at End of Run |
|---|---|---|---|---|---|---|---|---|---|
| **3 × 700,000-cir-mil Round, Shielded, Paper Binder** | | | | | | | | | |
| **Cable Complete** | | | | | | | | | |
| *A*—Alone | 23.7 | 1.184 | 1.184 | 1.182 | 1.182 | 1.180 | 1.176 | 1.171 | 27.9 |
| *B*—1 cable 6 in. away | 23.7 | 1.188 | 1.188 | 1.183 | 1.178 | 1.177 | 1.174 | 1.171 | 27.9 |
| *C*—2 cables 6 in. away | 23.7 | 1.190 | 1.189 | 1.184 | 1.180 | 1.179 | 1.176 | 1.169 | 27.9 |
| *D*—2 cables 3.5 in. away | 23.7 | 1.190 | 1.190 | 1.189 | 1.187 | 1.187 | 1.183 | 1.175 | 27.9 |
| **Sheath Off** | | | | | | | | | |
| *E*—Alone | 23.7 | 1.085 | 1.083 | 1.081 | 1.077 | 1.076 | 1.075 | 1.072 | 27.9 |
| *F*—1 cable 6 in. away | 23.7 | 1.082 | 1.084 | 1.081 | 1.077 | 1.075 | 1.075 | 1.073 | 27.9 |
| *G*—2 cables 6 in. away | 23.7 | 1.087 | 1.085 | 1.083 | 1.079 | 1.078 | 1.075 | 1.075 | 27.9 |
| *H*—2 cables 3.5 in. away | 23.7 | 1.105 | 1.098 | 1.095 | 1.093 | 1.093 | 1.090 | 1.088 | 27.9 |
| **3 × 700,000-cir-mil Round, Shielded, Steel Binder** | | | | | | | | | |
| **Cable Complete** | | | | | | | | | |
| *A*—Alone | 22.9 | 1.210 | 1.229 | 1.241 | 1.231 | 1.217 | 1.203 | 1.196 | 27.7 |
| *B*—1 cable 6 in. away | 22.9 | 1.208 | 1.228 | 1.245 | 1.233 | 1.218 | 1.205 | 1.192 | 27.7 |
| *C*—2 cables 6 in. away | 22.9 | 1.210 | 1.226 | 1.244 | 1.232 | 1.219 | 1.203 | 1.194 | 27.7 |
| *D*—2 cables 3.5 in. away | 22.9 | 1.212 | 1.231 | 1.249 | 1.229 | 1.219 | 1.205 | 1.200 | 27.7 |
| **Sheath and Steel Binder Off** | | | | | | | | | |
| *E*—Alone | 24.1 | 1.093 | 1.092 | 1.090 | 1.088 | 1.086 | 1.084 | 1.082 | 27.0 |
| *F*—1 cable 6 in. away | 24.1 | 1.091 | 1.092 | 1.090 | 1.088 | 1.086 | 1.085 | 1.080 | 27.0 |
| *G*—2 cables 6 in. away | 24.1 | 1.097 | 1.095 | 1.089 | 1.089 | 1.086 | 1.084 | 1.083 | 27.0 |
| *H*—2 cables 3.5 in. away | 24.1 | 1.110 | 1.107 | 1.105 | 1.105 | 1.105 | 1.102 | 1.097 | 27.0 |

comparison between measured and calculated results since the magnetic field is geometrical and undistorted.

The total losses of 3-conductor cable consist of the following component parts:

*a.* Conductor loss at zero frequency.
*b.* Skin effect loss in conductor.
*c.* Proximity loss in conductor.
*d.* Shielding tape loss (if any).
*e.* Metallic binding tape loss (if any).
*f.* Sheath loss.

For all practical purposes these component losses are directly additive and can be calculated separately. The method of conducting the calculations will be outlined briefly and necessary references made.

*Skin effect loss* has been fully dealt with by Dwight ("Skin Effect and Proximity Effect in Tubular Conductors," A.I.E.E. Trans., v. 41, 1922, p. 189–95). A. W. Evan later published curves based upon Dwight's work (p. 250 of "A Set of Curves for Skin Effect in Isolated Tubular Conductors," *G. E. Rev.*, v. 33, 1930). As an approximation the skin effect of a sector conductor is assumed as equal to that of a round conductor of the same cross section.

*Proximity effect loss* has also been dealt with by Dwight (p. 535 of "Proximity Effect in Groups of Round Wires," *G. E. Rev.*, v. 30, 1927). His formulas are somewhat difficult to handle but short cut methods will be obvious to those who wish to go into the subject seriously. In the study under discussion, the proximity effect of sector conductors was assumed equal to that of equivalent round, solid bars of the same total cross section and resistance, and with the same thickness of insulation. This ignores the contact resistance of stranding and, of course, gives maximum proximity effect.

*Shielding and binding tape losses* were estimated on the assumption of continuous metallic cylinders of the same diameter and thickness, and twice the resistivity of the metal tapings. Clark and Shanklin developed the method used for calculating shielding tape loss ("High-Tension Single-Conductor Cable for Polyphase Systems," A.I.E.E. Trans., v. 38, 1919, p. 917–69). The cylinder of binding tape was assumed in parallel with and part of the lead sheath.

*Sheath losses* have been fully dealt with by Dwight ("Proximity Effects in Cable Sheaths," A.I.E.E. Trans., v. 50, 1931, p. 993–8). R. W. Atkinson presented a more convenient short cut method in the discussion of Dwight's paper (A.I.E.E. Trans., v. 50, 1931, p. 998).

A comparison of the measured and calculated component losses for a number of the cables without magnetic binder listed in Table II is given in Table IV. It will be noted that with small size conductors, sheath loss is about 3 to 4 times calculated maximum proximity loss, while with large conductors it is approximately equal to proximity loss. Also, skin effect loss is about $^4/_5$ of this proximity loss. This means that with small conductors sheath loss predominates and proximity loss is not of much importance, while with large conductors proximity loss is of greater importance.

Now, skin effect loss and sheath loss are fixed quantities, determined by the physical dimensions of the cable and beyond the control of the manufacturer. Proximity loss, on the other hand, is variable and is the only component that gives the manufacturer any chance at all to reduce total losses appreciably. The range over which the manufacturer has such possible control is shown by the maximum and minimum curves in Fig. 2. When it is remembered that the carrying capacity of the cable varies as the square root of the losses it is at once apparent that there is only limited scope for improving the carrying capacity of 3-conductor cables by controlling proximity loss. From a practical standpoint it is of importance only with conductors of large size.

Cable with magnetic binder will be discussed later but it might be pointed out that here, also, proximity loss is the variable factor. (The term "proximity loss" for magnetic binder cable is meant to include all additional mutual and self-inductive losses in the conductor caused by eccentric magnetic field distortion.) In Fig. 2 it is shown that with magnetic binder there is a wider range for controlling losses by controlling proximity effect and, consequently, this effect is of more importance in this case.

**Table IV—Comparison of Theoretically Calculated and Measured Losses in Nonmagnetic, 3-Conductor Cable**

| | Calculated Extra Losses % | | | | | | | Measured Extra Losses % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cable No. † | Sheath Loss | Binding Tape Loss | Shielding Tape Loss | Skin Effect Loss | Proximity Effect Loss | Total | Copper Temp Deg C | Sheath Loss | Binding Tape Loss | Remaining Losses | Total |
| 2 | 3.4 | | | 1.3 | 1.6 | 6.3 | 33 | 4.0 | | 2.0 | 6.0 |
| 3 | 3.0 | | | 1.1 | 1.0 | 5.1 | 52 | | | | 4.0* |
| 4 | 3.2 | | | 1.3 | 1.6 | 6.1 | 33 | 4.0 | | 1.0 | 5.0* |
| 13 | 3.6 | 0.8 | 0.7 | 1.3 | 1.6 | 8.0 | 33 | 4.0 | 0 | 2.0 | 6.0* |
| 14 | 4.2 | 0.9 | 0.9 | 1.2 | 1.2 | 8.4 | 41 | | | | 5.0* |
| 15 | 3.5 | 0.7 | 0.7 | 1.1 | 1.1 | 7.1 | 47 | | | | 6.0* |
| 16 | 4.1 | 0.9 | 0.8 | 1.3 | 1.0 | 8.1 | 33 | 4.0 | 0 | 2.0 | 6.0 |
| 18 | 4.1 | 0.5 | 0.8 | 1.3 | 1.0 | 7.7 | 33 | 5.0 | 0 | 1.0 | 6.0 |
| 19 | 3.2 | 0 | 0.7 | 1.3 | 1.6 | 6.8 | 33 | | 0 | | 5.0* |
| 20 | 4.1 | 0 | 0.8 | 1.3 | 1.0 | 7.2 | 33 | 4.0 | 0 | 2.0 | 6.0* |
| 21 | 3.2 | 0 | 0.7 | 1.3 | 1.6 | 6.8 | 33 | 3.0 | 0 | 2.0 | 5.0* |
| 40 | 9.5 | | | 4.8 | 6.3 | 20.6 | 33 | 10.0 | | 8.0 | 18.0 |
| 42 | 8.8 | | | 4.8 | 6.3 | 19.9 | 33 | 8.0 | | 4.0 | 12.0* |
| 52 | 10.0 | 2.1 | 1.7 | 4.8 | 6 3 | 24.9 | 33 | 11.0 | 0 | 9.0 | 20.0 |
| 56 | 7.0 | 0.4 | 1.7 | 4.8 | 6.3 | 20.2 | 33 | 7.0 | 1.0 | 4.0 | 12.0* |
| 58 | 7.0 | 0 | 1.7 | 4.8 | 6.3 | 19.8 | 33 | 8.0 | 0 | 5.0 | 13.0* |
| 66 | 7.9 | 2.0 | 2.3 | 5.6 | 7.0 | 24.8 | 28 | 9.5 | 1.5 | 10.0 | 21.0 |
| | 6.0 | 1.5 | 1.5 | 4.2 | 5.4 | 18.6 | 69 | | | | 16.0 |
| | 5.5 | 1.3 | 1.3 | 3.8 | 5.1 | 17.0 | 83 | | | | 15.0 |
| 68 | 7.6 | 1.8 | 2.2 | 5.4 | 6.6 | 23.6 | 33 | 9.0 | 1.0 | 9.0 | 19.0 |
| 75 | 14.2 | 0 3 | 3.4 | 9.2 | 11.2 | 38.3 | 27.5 | 14.0 | −1.0 | 22.0 | 35.0 |
| 76 | 14.2 | 0.3 | 3.4 | 9.2 | 11.2 | 38.3 | 27.5 | 16.0 | 1.0 | 9.0 | 26.0* |

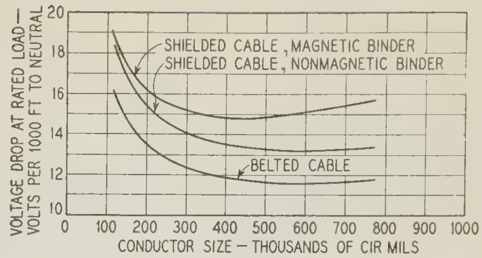
† See Table II for description of cables.
* Low loss cables. Subtract proximity loss from total calculated loss for comparison. All other cables have higher loss but never maximum solid bar proximity loss.

## Controlling Proximity Loss of Standard Conductors

The manufacturers have made a complete study of this problem and it has been demonstrated that proximity loss of stranded conductors is governed entirely by contact resistance and distribution of circulating (eddy) currents between strands. Of these 2 factors, distribution of circulating current is the most important from a practical standpoint. Anything that tends to distribute this cross current between strands uniformly along the strand length

**Fig. 5. Voltage drop at rated load of 3 - conductor cables for 15-kv service**

9 cables per duct bank




and not allow it to concentrate in spots at the strand surface will reduce proximity loss. In other words, uniform surface contact between strands both laterally and circumferentially is the most practical way of controlling proximity loss, the normal, inherent contact resistance being sufficient for this purpose.

This being accomplished, there will be still further reduction in proximity loss by increasing contact resistance between strands. In fact, perfect insulation between strands reduces proximity effect to a minimum regardless of method of stranding by entirely eliminating cross currents, as demonstrated by tests on cables with enameled strands (cables Nos. 74 and 76, Table II).

The most definite method of controlling contact resistance is to insulate the strands with enamel or other hard insulating films. Oxidized and tarnished strand surfaces will, under certain conditions, increase contact resistance but since this resistance also depends upon pressure between strands and both the degree of oxidation and the pressure at points of contact are difficult to control uniformly, this method has not worked out well.

As a matter of fact, complete or partial insulation of strands, as described above, is hardly desirable for a number of reasons. It makes sweating of connectors difficult and introduces impurities into the cable. Fortunately, this method is not necessary and proximity loss can be adequately and more practically controlled by uniform distribution of cross currents, accepting normal contact resistance.

The usual method of stranding is to lay alternate layers of strands in opposite directions. When the strands are tightly and compactly applied in this way but not rolled or crushed it leads to relatively high proximity loss because the circulating current is concentrated at those points of contact where the strands cross. Rolling or crushing the conductor will increase the area of strand contact and reduce the concentration of current. The more compactly the strands are crushed, particularly the outer layers, the greater will be the reduction in proximity loss.

When the layers are in the same direction but not crushed there is line instead of point contact between strands and uniform lateral distribution of cross currents. Where a flexible conductor is desired this is an effective way of reducing proximity loss. This type of stranding, however, tends toward a loose and nonuniform arrangement of strands which in many cases is undesirable.

The most practical method of controlling proximity loss is to strand all layers in the same direction and crush each layer by rolling as the conductor is built up. This results in a neat, compact conductor cross section under good factory control and reduces proximity loss practically to the theoretical minimum. This compact rolling of strands also reduces the cable cross section and cost.

Cables Nos. 17, 35, and 69 in Table II have this compact arrangement of strands. The minimum curves in Fig. 2 are based upon theoretical minimum losses with zero proximity loss. If cables Nos. 17, 35, and 69 are compared with the minimum curve for cable with nonmagnetic binder it will be seen that there is very good agreement and that the proximity loss of these cables must have been close to zero. In making this comparison the smaller diameter of the compact strand cables and the resulting decrease in sheath loss should be taken into account.

## Other Points in Connection With Losses

A study of the measured and calculated component losses in Table IV brings out a number of interesting points. It will be seen that the measured and calculated sheath losses agree quite well and that the proximity loss is the only variable, falling between maximum, solid bar, and zero proximity losses, as determined by the method of stranding and the condition of the strands. The same comparison is shown in Fig. 2, where the maximum curves represent maximum measured proximity loss for stranded conductors and is always less than the solid bar proximity loss given in Table IV. It will be noted that only the points for unimpregnated cable and round conductor cable of larger diameter than sector fall above the maximum curves in Fig. 2.

It is not possible to calculate theoretically the component losses in cable with magnetic binder because of the field distortion. An empirical study of such cable, however, leads to some interesting conclusions. Component losses were measured for most of the cables with magnetic binder in Table II. Space does not allow inclusion of these data but a typical set of measurements is given in Table I.

It will be noted that sheath loss is less and proximity loss greater than for a corresponding cable with nonmagnetic binder. The magnetic binder acts as a shield and reduces the flux interlinkages with the sheath, thus reducing sheath loss. At the same time, this binder distorts the field inside the cable and causes an increase in proximity loss. These 2 changes more or less balance and it is for this reason that there is little difference in total losses of magnetic and equivalent nonmagnetic binder cables.

It is possible to shield the sheath entirely by wrapping the magnetic binder tape with little or no space between tapes. Cable No. 62 was made in this way and the measurements with and without sheath were exactly the same. The total losses in cable No. 62 were, however, practically the same as those of standard cable with the binding tape spaced $^1/_2$ to $^5/_8$ in. The reason for this was that while sheath loss was eliminated there was a corresponding increase in proximity loss from field distortion.

The steel binding tape in cable No. 62 was of ordinary commercial grade in which the magnetic and

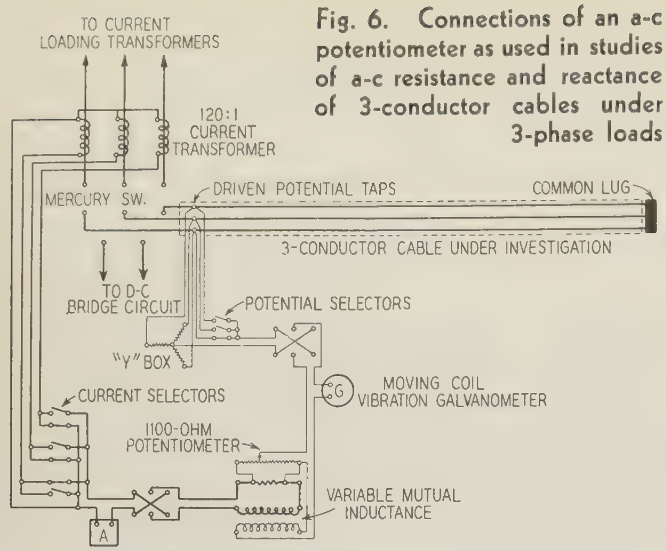



**Fig. 6. Connections of an a-c potentiometer as used in studies of a-c resistance and reactance of 3-conductor cables under 3-phase loads**

electrical properties were disregarded. Cables Nos. 63 and 65 were constructed exactly the same with the exception that high resistivity transformer steel (*DX*) and high permeability (Nicaloi) steel were used, respectively. Comparison of these 3 cables shows that the magnetic and electrical properties of the binding tape have no practical effect on total losses. It also shows that the magnetic losses in the binding tape itself are negligibly small. These results are due to the very large "air gap" in the magnetic path.

Proximity loss predominates under all conditions in cable with magnetic binder. It is for this reason that there is a greater spread between minimum and maximum loss curves for magnetic binder cable in Fig. 2. With cable having nonmagnetic binder sheath loss, a fixed quantity plays a prominent part and proximity loss is reduced. This leads to a lesser spread between the maximum and minimum curves.

## Appendix A—Test Method Used by Electrical Testing Laboratories

The length of sample selected for the test specimens was 15 to 20 ft, the preliminary investigations having indicated that measurements could be made on specimens of this length with sufficient accuracy to report final values reliable to better than 0.5 per cent. Accordingly, the procedure was developed particularly for specimens of this order of length, though it is equally applicable to longer specimens.

After cutting specimens to the desired length, the lead sheath was removed from 4 in. of cable at one end and 15 in. at the other end. At the 4-in. end, the insulation, binder tape, shielding tapes, etc., were cut off square with the end of the lead, leaving only the 3 bare conductors protruding. These bare ends were then sweated into a large cup made from copper pipe, so placed that the cup and solder came within about $^1/_8$ in. of the end of the sheath.

At the other (15-in.) end, the binder tape or belt insulation was removed and cut off smoothly at the edge of the sheath. The insulation was then removed from the outer 2 in. of each conductor and individual lugs were sweated on. The 3 conductors then represented a *Y* or star connected system or load.

Two inches in from the edge of the lead sheath at the "15-in." end, 3 holes $^3/_8$ in. in diameter were drilled through the sheath, binder, and shielding tapes—one hole being centered over the "back" of each of the 3 conductors. At the center of these holes a smaller hole was drilled through the insulation and into the conductor for about $^1/_4$ in. Copper pins were then driven down into these openings to serve as potential taps.

The fall of potential along each conductor from the driven potential tap to the common end (i. e., cup end) was measured in terms of resistance and reactance by means of an a-c potentiometer and mutual inductor connected in the secondary circuit of a current transformer, the primary winding of which was connected in series with the conductor being measured.

A few preliminary measurements showed that comparatively large errors might be introduced by using a potential lead connected to the "neutral" point at the cup end of the cable. An artificial neutral was, therefore, provided with the aid of 3 equal noninductive 10-ohm resistors connected across the driven potential terminals; all question of induced electromotive force in the neutral potential lead was thereby eliminated. At the same time, the 10-ohm resistance was high enough to avoid any troublesome correction due to shunting current and yet low enough not to reduce galvanometer sensitivity. A schematic diagram of the general test circuit is shown in Fig. 6.

The use of this potentiometer arrangement makes it possible to determine the equivalent resistance and reactance of the cable directly in terms of a standard resistance and standard mutual inductance. For instance, if the symbols used are as follows:

$T$ = current transformer ratio
$M$ = setting of mutual inductor, henries
$S$ = standard resistor, ohms
$P$ = total resistance of potentiometer, ohms
$N$ = resistance of that portion of the potentiometer inserted to obtain a balance, ohms
$K$ = tangent of angle introduced by current transformer
$w$ = angular velocity, radians per second

the relations for the effective resistance and reactance of the specimen of cable under investigation are:

$$R = \frac{1}{T} \cdot \frac{NS}{S+P} - \frac{wMK}{T}$$

and

$$wL = \frac{wM}{T} + \frac{K}{T} \cdot \frac{NS}{S+P}$$

where

$R$ = effective resistance, ohms, and
$wL$ = reactance, ohms

Since the reactance of the cables measured was of the same order as the resistance, the use of current transformers with phase angles not larger than 10 min of arc ($K = 0.003$) makes the last term of each of these expressions negligible. The relations then become

$$R = \frac{1}{T} \cdot \frac{NS}{S+P}$$

$$wL = \frac{wM}{T} \text{ or } L = \frac{M}{T}$$

which are the equations used in the determination of effective resistance and reactance in these measurements.

### Table V—Results of Interlaboratory Checks

Data in the same line are for cables of identical construction

| Laboratory | Cable Number* | A-C:D-C Resistance Ratio | Laboratory | Cable Number* | A-C:D-C Resistance Ratio |
|---|---|---|---|---|---|
| I | 8 | 1.08 | II | 11 | 1.14 |
| I | 24 | 1.09 | IV | 26 | 1.16 |
| I | 25 | 1.11 | II | 27 | 1.16 |
| III | 32 | 1.08 | I | 33 | 1.10 |
| III | 31 | 1.09 | I | 34 | 1.10 |
| I | 36 | 1.13 | II | 37 | 1.27 |
| I | 49 | 1.13 | III | 50 | 1.13 |
| I | 48 | 1.13 | IV | 51 | 1.14 |
| I | 54 | 1.10 | III | 55 | 1.10 |
| I | 59 | 1.23 | V | 61 | 1.24 |
| I | 66 | 1.23 | V | 67 | 1.21 |
| I | 71 | 1.42 | V | 73 | 1.42 |

* Identification number. See Table II for description.

By means of the mercury switch shown in Fig. 6, a change could be quickly made from the a-c potentiometer to a d-c double bridge for the measurement of the ohmic resistance of the conductors. The use of a reflecting galvanometer with the Kelvin bridge made it feasible to measure these resistances to better than 0.1 per cent.

In making measurements of this nature it is possible to work either with the cable at or near room temperature or after heating under load to a temperature approximating operating temperature. However, due to the necessity for getting results promptly the measurements were made with the cable as nearly as possible at room temperature. This required making the measurements quickly in order to avoid heating.

When making a series of measurements it was the practice to take the d-c resistance before and after each a-c measurement. In general, these did not differ by more than one per cent even at the high current loads. The average of the 2 d-c resistance measurements was then used in the computation of ratios involving the d-c resistance.

Following each test the data were computed and curves plotted. If the results appeared satisfactory, the lead sheath was removed and a second test made. The cable was then torn down step-by-step, the measurements being repeated at each step. In this manner it was anticipated that the losses could be analyzed as to their sources.

## Appendix B—Interlaboratory Checks

In order to eliminate the possible effects of differences between various laboratories, numerous check tests were made in which the same or similar pieces of cable were measured in each of 2 or more laboratories. The general results of these interchecks, Table V, showed good agreement although there were some exceptions. It is considered that such measurements should show agreement to within 1 to 2 per cent. Where individual measurements have shown deviations from the group which exceed this amount, the data have not been included in the graphic presentation in Fig. 2.

## Appendix C—Check Measurements Against Field Test

Early in 1931 a field test was arranged by W. H. Cole of the Edison Electric Illuminating Company of Boston. The cable under test had been manufactured in 1930 and at that time a-c resistance and reactance measurements were made on specimens of the cable both at the Electrical Testing Laboratories and in the manufacturer's laboratory. The final installation covered 37,020 ft of this cable and offered an excellent opportunity to check the results obtained in the laboratories on short samples.

The results of these measurements together with the original E.T.L. and factory results are shown in Table VI. It will be noted that a very close agreement is shown between all measurements with one exception where the factory measurements were made on the cable on a reel (instead of being laid out straight). It is likewise interesting to note that these field measurements show the same dependence upon phase rotation which had been found earlier in the laboratory.

### Table VI—Check Against Field Tests of Installed Cable

All values expressed as a ratio to the d-c resistance

| Tested | Length of Cable Tested | Current Load, Amps per Phase | A-C Resistance | 60-Cycle Reactance |
|---|---|---|---|---|
| E.E.I. Co. of Boston | 37,020 ft | 204.3 | 1.113 | 1.816 |
| | | 291.3 | 1.114 | 1.822 |
| | | 392.2 | 1.118 | 1.835 |
| | | 442.9 | 1.112 | 1.822 |
| | | 443.6* | 1.124* | 1.812* |
| Manufacturer | Short sample | 400 | 1.128 | |
| | | 600 | 1.128 | |
| | Full reel | 600 | 1.155 | |
| E.T.L. | 15 ft | 200 to 600 | 1.12 | 1.82 |

Note: 3 × 700,000-cir-mil, sector conductor cable, 220 mils paper, Type *H*, nonmagnetic binder.

Data from field tests furnished through the courtesy of W. H. Cole, superintendent, street engg. dept., Edison Electric Illuminating Company of Boston, Mass.

* This test made after reversing phase rotation to agree with rotation of conductors viewed from supply end.

# On the Schooling of Engineers

**Two types of students, one fundamentally interested only in engineering, and the other more deeply interested in and capable of leadership, are considered in this paper. For both, a broader training in the humanities is urged. Among the numerous points which it is stated should be brought to the attention of the student engineer is the necessity of realizing that human relationships, which cannot be reduced to a science, are among the most important considerations in later life.**

By
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WHEN I last addressed an audience on the subject of the schooling of engineers, I spoke as an executive who retained so much of his inherited bent toward engineering that he still comprehended the operation of a student mind; a mind exceedingly desirous of engineering success and, to that end, rejecting as impedimenta all offerings of schooling in what we have for ages called the humanities. The intervening 8 years since that address have pushed me further from engineering, and submerged me deeper in problems for which I have an inherited dislike—problems of finance, of law, of politics; problems which do not admit of an engineering solution; problems of which no complete solution satisfying every factor is possible; problems where no rule of physics or mathematics will aid a solution, because the relations of the factors are neither reasonable nor constant—because the factors are of disproportionate values, measurable only on the unstable scale of their reactions on human beings. And in these years I have been confirmed in my earlier opinion that there remains something to be done toward a broadened education of those

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students who have chosen to be engineers, who have on them the urge to be engineers, and whose innate mentality finds happiness in exactness of expression and completeness of reasoned result.

### Ability in Nonengineering Lines Desirable for Success

The purely engineering mind does not take kindly to the humanities. The student who seeks and rejoices in a complete solution of a technical problem, tends to believe that such a solution should be possible for every problem. Wherefore he is apt to belittle an offered study in which the preceptor is forced to admit that the answer in most cases may be either "yes" or "no," that there will be in every case an unsatisfied remainder. Nevertheless, the engineer who rises above purely technical achievement must solve problems in human nature. He has then ceased to be concerned solely with the qualities of matter, and the forces inanimate. If he is a notable success in his engineering, he will surely in time be offered opportunities wherein he will need the aptness of the executive who knows that it is imperative to decide quickly, even though the decision may be imperfect; he will see that he must avail himself of other human beings as assistants or delegates, even though these are not to his heart's desire; and find that he must recognize and allow for an infinity of variables, requiring in him at the one end of his knowledge of the humanities, a silent comprehension of mass psychology, and at the other end an occasional outspoken exhibition of what is colloquially called "horse sense."

If our school intent is only to produce human calculating machines, interpreters of rigid specifications, supervisors of exact tests, there is nothing to criticize in the engineering training which is now offered by the schools. Furthermore, those schools which now require that there shall be a certain devotion, in the earlier years, to what I shall continue to call the humanities, already recognize that a thorough technical schooling is not the end-all of their effort. I assume that we desire scholarly engineers, and not merely expert technicians.

As one who has neither taught nor studied in any university I speak with deference to those who from year to year are seeking to send out graduates broadly equipped for life in this complex world; and of all of you I ask recognition that I speak as one who has been the immediate employer of many school trained engineers. Among these I have found representatives of each extreme; I have found the man who did not seek to be more than an accurate calculator, estimator, inspector, content if his field results agreed with his desk figures. And I have found the man who looked upon engineering skill as an aid toward leadership—who sought appreciation from those who could measure and value him as an all-around man of affairs, doing good work for his world and incidentally doing well for himself. The first man sought, as his compensation, a fair return on his investment in engineering education. The other held the value of his service to be the measure of his gain, and was willing to venture boldly and be judged by results. No schooling can guarantee to produce the latter type. The possibility must be born in the boy. But the schooling may (and I say it should) extend the mental horizon and increase the social value of the first type.

Assuming that the social sciences are to be presented to engineering scholars, the teacher must recognize that trait (already noted) of the student engineer mind: an impatience of all incomplete solutions, even though the acceptance of an incomplete solution may open out an impasse. If teachers, who cannot modify their technique, are assigned to this duty, the time set aside for study of social subjects by student engineers will be wasted, with the probability of forbidding future interest in the despised subjects. Your student recognizes immediately the value of (let us say) mathematics. He is willing to follow the mathematician into pure physics, the excursions into which have to him the character of research. Those humanities of which he can see possible uses to his first purpose, are more likely to be tolerated or welcomed by the student. Let us see what these are and how they should be presented.

### Language—Most Important of the Humanities

Let us consider first language; inability to speak and write English is entirely too common among engineer scholars, and after school days will be recognized by the young engineer as a handicap. The courses in English which are offered as parts of a literary course, are definitely not attractive. Still more so is this the case with a literary college course in any foreign language. I hold that at least one foreign language should be required, up to the point of reading it. The foreign language course is rdinarily directed toward the acquisition of facility in speech and in writing. The engineering student need not seek fluency of speech. He needs only the necessary vocabulary and knowledge of grammar sufficient to permit his intelligent reading of engineering literature. And the reflex from the limited study of the foreign language (especially of its grammar) will contribute to precision in English.

I do not know how English should be taught to engineering students. Our public schools nowadays start off on the wrong foot. The young child acquires a talking and reading acquaintance with his language, but is not taught its grammar nor given a vocabulary greater than he will acquire in his everyday life. English was taught otherwise to me. At 10 years of age I knew that prepositions governed the objective case and that adverbs qualified verbs, adjectives, and other adverbs. Also, I knew that "to admit" was not the equivalent of "to acknowledge" and that "a remainder" was not ipse facto "a balance"; and so forth and so forth through a hundred exhibits that my memory could produce were it taxed to do so. That method is one for childhood; not for 18-year-olds. But I persist in believing that the study of English can be made interesting, and I know that skill in the use of language should be rated at least as highly as skill in, say, the use of the slide rule.

## Accounting and Economics Should Be Taught

Beginning with English and with at least one foreign language, I would continue with accounting and economics. Accounting has many variations but its principles are the same wherever taught. Its usefulness as an engineering tool should be evident to the student. There should be included a course in the analysis of costs of completed work; and somewhere therein there should be a warning that the synthesis of costs of proposed work is not necessarily a complement to analysis.

As to economics—I cannot find that there is any accepted science of economics. Therefore it cannot be taught as a science. The engineering student is inclined to make a jest of economics. I do not blame him. When he finds that one teacher insists that commercial activity is proportional to the quantity of a circulating medium; that another utterly disregards such proportionality; that a third says there is no inherent value in gold outside of its limited use in the arts; while a fourth teaches that the control of gold means the control of commerce—these differings of doctors provoke the laughter of the student engineer. The absence of an accepted vocabulary of economics is another defect. It disconcerts a student to find that a term may mean something quite different when used by another writer, and that even the one writer may impose different meanings thereon. I would make the presentation of economics almost sketchy, possibly a sequence of lectures setting forth the several theories which have been formulated and offered to the world, and comparing their agreements and contradictions. I would tie my study of economics into history, showing the recognizable errors of the past. But I should not recommend to the engineering student the acceptance of any economic theory whatever. Let him see that his future work will inevitably be restrained or facilitated by so-called economic conditions, and that his recognition of conditions at any time existing, and the trends thereof, will be helpful to him in the long game of life.

## History, and Its Relation to Other Humanities

Naming now those humanities which are not useful in the day's work of the engineer, in my opinion the most important of these is history. It should be taught as it is not taught today. The historian suffers from a complex similar to that of the narrow engineer in that he feels laid upon him the burden of finding the facts and making a record thereof. To me the charm of history is not in proving who wrote such a letter, or broke such a treaty, but in showing the origins and scopes of social movements throughout the ages. Into history there can be tied the recognition of economic forces. If we are to teach history of the current year it should be shown why one nation needs for its safety, or even for its existence, free and world-wide access to the seaways; whereas the vital sea need of another nation is only that there shall be no interception on the narrow seas of the colonial grain with which, like Rome of old, it must feed its people. It should be shown how engineering progress, beginning with the earliest roads and irrigations, has affected the fate of peoples; how in 40 years of the nineteenth century the British invention and adoption of steam power changed the régime of a nation, and indeed of an empire; and how the development of communications and of electric transmission of power has in this century altered the social and economic balances of the habitable world. I would make history the backbone (so to speak) of all teaching of the humanities. To the student engineer a presentation of arrived results, though these have been neither sought nor predicted, has attraction which in his mind is missing from pure speculation.

Beyond these recommendations I have no present mind to go. If history be taught as it should be taught, there will be necessary recognitions not only of the economics involved but of the personal and mass psychology involved in the changing conditions of races, and peoples, and governments. Even philosophy can and should be shown to have had its influence upon that sequence of events which we call history. And you cannot crowd a personally necessary training in techniques, and also an education in all the humanities into the 4-year course to which we are at present committed. I do not suggest making that course longer. If circumstances permit our student to spend further time at school I would rather, after he completes his 4-year course, have him go into the field for a couple of years; and thereafter come back with a reasoned choice of the study or studies he wishes to pursue.

## Versatility Essential to Leadership

Throughout this talk I have had in mind the probability that the successful engineer will in later life find himself busy in work which is not pure engineering, work in which his engineering training will teach him to analyze and organize its processes, but in which he is dealing with human beings whose desires change from year to year and whose rated capacities are not engraved upon individually attached nameplates. Our engineer may be a partner in a manufacturing or constructing firm, meeting problems in finance, in personnel, and in sales methods. He may be offered (or may have pressed upon him) public duties to his city, his state, or even to the nation. In any of these environments he will be helped by his engineering training, but if he is to be successful, he must refrain from the belief that human beings can be depended upon to do what they should do, subject to set factors of safety. He cannot even restrict himself to his own commercial, or social, or governmental functions. If he is to lead, he must see broadly what is going on in each contiguous phase of life. If he is depended upon by thousands of employees, or by city, or state, or national populations to guide affairs in the way they should go, he must recognize that leadership does not lead if it restricts itself to narrow duties, if it binds itself to a formula and fails to mark and follow the expediency, or the necessity, inherent in immediately observed conditions.

# Coaxial Communication Transmission Lines

**A nonmathematical discussion of the mechanism whereby energy may be transmitted over long distances at high frequencies by the use of "coaxial conductors" is presented in this paper. A coaxial system consists of a cylindrical conducting tube within which a smaller conductor is coaxially placed. Such conductors, which reduce interference and cross-talk, are applicable for the transmission of telephone, telegraph, and television signals over a very wide range of frequencies.**

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THE technical possibilities of the use of "coaxial conductor" systems for bands of frequencies as wide as 1,000,000 cycles or more are discussed in a recent paper by L. Espenschied and M. E. Strieby ("Coaxial Conductor Wide Band Transmission Systems," ELECTRICAL ENGINEERING, volume 53, Oct. 1934, page 1371–80). A comprehensive mathematical discussion of coaxial transmission lines is given by the author in another paper ("The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," *Bell System Technical Journal*, volume 13, Oct. 1934, page 532–79). The present paper attempts to give a nonmathematical discussion of the physical mechanism by which physical energy is conveyed along a coaxial pair, dissipated in it, or transferred between it and other neighboring systems. It is believed it will be of interest to engineers who may not wish to follow through the mathematical treatment.

## Mechanism of Transmission of Energy

A coaxial transmission system is comprised of a central wire surrounded by a coaxial shield which is employed as the return conductor. The laws of transmission of energy along such a system do not differ in any essential respect from those governing a parallel pair. If one member of the parallel pair were to be replaced by a cylindrical shell coaxial with the other wire and at the same distance from it, the capacity per unit length would become about twice as great and the inductance about $^1/_2$ as great, so that at high frequencies, where the influence of the resistance on the surge impedance of the line is negligible, the surge impedance of the coaxial line is about $^1/_2$ the surge impedance of the parallel pair.

Within a coaxial pair (figure 1) the lines of magnetomotive intensity $H$ are coaxial circles and the lines of electromotive intensity $E\rho$ are substantially radial. The word "substantially" is used because although most of the energy travels *along* the pair, a slight amount of it moves radially into the imperfect conductors, where it is dissipated in heat.

By electromagnetic theory this radial movement of energy implies the presence of the longitudinal component $E_l$ of the electromotive intensity parallel to the conductors. This $E_l$, negligible for most purposes, is an important factor in calculating the a-c resistance of coaxial pairs and in matters of interference and cross-talk. Being tangential to the cylindrical boundaries between different mediums comprising the coaxial pair, it is continuous across them while the radial component $E_\rho$ is practically annihilated on entering the conductors. In the conductors themselves $E_l$ and $H$ constitute the principal field, and energy moves there almost exclusively outward (or inward, as the case may be) and not lengthwise as in the dielectric between the conductors. Because of heavy absorption of energy by the conducting substance, the field is rapidly attenuated in this outward direction.

A quantitative idea of the rate of decay can be gained by considering the simplest case of a plane wave, in which $E$ and $H$ are uniform all over the wave front (figure 2). The formulas for the propagation of such a wave in a homogeneous medium are very similar to those of wave propagation in transmission lines, the permeability $\mu$ playing the rôle of series inductance, while the conductivity $g$ and the dielectric constant $\epsilon$ take the part of the shunt conductance and capacity, respectively (see figure 3). In metallic substances the conductivity is large and the dielectric constant can be neglected, so that the propagation constant is expressed simply as $\sqrt{j\omega\mu g} = \sqrt{\pi\mu f g}\,(1 + j)$ nepers per centimeter. (Here the conductivity $g$ is expressed in mhos per centimeter and the permeability $\mu$ in henries per centimeter. Also, $\omega = 2\pi f$ where $f$ is the frequency.) In copper, for instance, $\mu = 1.256 \times 10^{-8}$ henries per centimeter and $g = 5.80 \times 10^5$ mhos per centimeter, so that at 1,000,000 cycles the attenuation constant is 151 nepers or 1,315 decibels per centimeter. The phase change is 151 radians per centimeter, so that the wave length in copper is 0.415 millimeters. Both

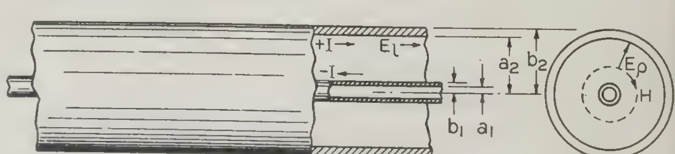


**Fig. 1. In a coaxial transmission line the lines of magnetomotive intensity are circles and those of electromotive intensity not very different from radii**

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the attenuation and the phase change are thus exceedingly rapid.

In the outer conductor of the coaxial pair the wave is not plane, but it could be regarded as such without introducing a serious error, because the "attenuation" (in the more general sense) of the wave due to the outward divergence is slight and the attenuation due to the energy absorption is very great. This fact will be useful when the shielding afforded by the outer conductor is discussed later in this paper.

A hollow conductor has an optimum thickness from the point of view of its resistance; this optimum thickness equals $^1/_4$ of the wave length for this particular metallic substance. If the conductor is made thicker while keeping the diameter of the active surface (that is, the surface of the greatest current density) fixed, the electric current in the added metal will flow in opposition to the original current and if the same total current is to be maintained, the current density must be raised throughout the conductor, thus resulting in increased energy losses and increased effective resistance. (A somewhat different picture of this phenomenon is presented by S. A. Schelkunoff in "A Skin Effect Phenomenon," *Bell Laboratories Record*, volume 11, Dec. 1932, page 109–12.)

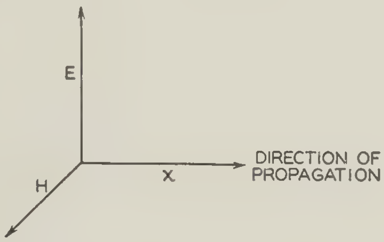


**Fig. 2. Relative orientation of the field components in a plane, plane-polarized electromagnetic wave**

## Interference and Cross-Talk

There has now been established a sufficient background for approaching the important problem of interference and cross-talk. Consider a coaxial pair above the ground (figure 4). The ground together with the outer conductor of the coaxial pair forms a parasitic transmission line so that in effect the system is comprised of 2 continuously coupled transmission lines, one carrying current $I$ and the other $I_g$.

The electromagnetic field of a radio station or of static is impressed upon the ground circuit and produces in it current $I_g$, which in its turn produces the voltage drop $E_t$ along the outer surface of the outer conductor of the coaxial pair. However, because of the rapid attenuation previously discussed, this gives rise to only an exceptionally weak "induced" voltage drop along the inner surface of the conductor. Besides, on the inner surface, the abrupt change in the properties of the medium causes almost a complete reflection, practically annihilating the magnetomotive intensity and doubling the voltage drop.

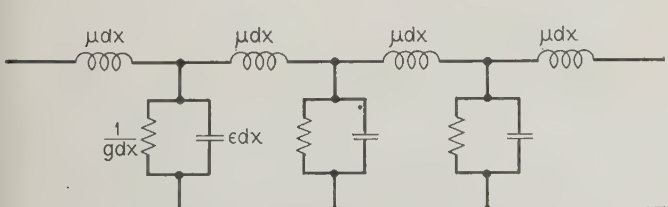


**Fig. 3. This equivalent circuit of a transmission line with distributed constants is a model of a plane wave traveling through a homogeneous, isotropic medium**

This matter of interference can also be considered from a somewhat different point of view. For all practical purposes the field of the coaxial pair does not extend beyond the outer surface of its outer conductor, and, similarly (except at very low frequencies) the field of the ground return line is limited by the inner surface of that same conductor. The outer conductor, therefore, represents the entire distributed mutual impedance between the 2 transmission lines. At zero frequency, this mutual impedance is the d-c resistance of the conductor, but otherwise it has a reactive component due to the magnetic interlinkage taking place within the space occupied by the outer tube. The mutual resistance between 2 coupled circuits can be measured by that average amount of dissipated energy which is proportional to the product of the electric currents flowing in those circuits, and similarly the mutual inductance can be gauged by that average amount of stored magnetic energy which is proportional to the product of those same currents. (The self-resistance of the circuit can be measured by that amount of dissipated energy, which is proportional to the square of the current in the circuit. An analogous statement applies to the self-inductance.) As the frequency increases the electric current $I$ of the coaxial pair tends to concentrate on the inner surface of the outer conductor and the current $I_g$ of the ground return line moves toward the outer surface. The 2 currents become more and more separated, the regions of high density of one overlapping the regions of low density of the outer, and the mutual energy of dissipation as well as the mutual electromagnetic energy are thereby diminished.

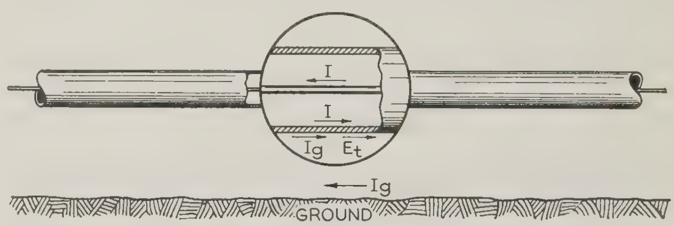


**Fig. 4. The outer conductor of the coaxial pair and the ground form a parasitic transmission line playing an important rôle in interference phenomena**

The problem of cross-talk between 2 coaxial pairs is quite similar. Besides the 2 given transmission lines there is a parasitic line comprised of the outer conductors of the 2 pairs. The induction takes place from one pair into this parasitic line and thence into the second pair. Obviously, this cross-talk is exceedingly small. It is largely because of this freedom from interference that the coaxial pairs have been used as lead-ins between antennae and radio stations and seem to be promising as broadband transmission systems.

# Recommended Transformer Standards

**A brief review of several important revisions and extensions of the A.I.E.E. standards for transformers recommended by the A.I.E.E. transformer subcommittee is presented herewith, in order that those interested may have an opportunity to become familiar with these recommendations and to offer helpful criticism before action on final standards is taken.**

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DURING the past 2 years the A.I.E.E. transformer subcommittee has made several important recommendations for additions to and changes in the A.I.E.E. transformer standards. Most of these relate to insulation levels and dielectric tests. Their purpose has been to bring the Standards up to date in line with the present art of lightning protection.

Insulation levels have been established, impulse testing recommendations formulated, low frequency dielectric tests revised, and a bushing flashover standard proposed. Timely recommendations covering permissible short time overloads for transformers also have been made.

The purpose of the present report is to summarize briefly these more important recommendations in order that the industry may become more familiar with them and may offer helpful criticism before action on final standards is taken.

## Insulation Levels

The first attempt of the subcommittee to supplement the present A.I.E.E. dielectric tests with impulse strength requirements was in 1930, when it was recommended[1] that transformer insulation in different voltage classes be coördinated with different numbers of line insulators. Later,[2] gap spacings were found to be a more convenient means of expressing the desired insulation level and the schedule of gaps now has been extended to include the distribution circuit voltages and also the 287.5 and 345 kv classes. At the last meeting of the subcommittee it was decided to list the insulation levels of transformers in terms of the gap spacing used for the impulse test rather than in terms of the coördination gap spacing. Table I gives a complete tabulation of coördination and test gaps.

The standard test gap used in making impulse tests consists of $^1/_2$-in. square-cornered square-cut rods coaxially spaced and overhanging their supports at least $^1/_2$ the gap spacing, and mounted on conventional insulators corresponding to the N.E.M.A.-E.E.I. (National Electrical Manufacturers' Association-Edison Electric Institute) standards giving a height above the ground plane[3] 1.3 times the gap spacing plus 4 in. (± 10 per cent tolerance). When gaps are used in the field to establish insulation levels they often are of other construction.

In establishing this schedule of test gaps it should be understood clearly that the subcommittee is only attempting to set up reasonable insulation levels for the design of transformers. It is not attempting to dictate to operating engineers the specific insulation levels that should be used in any particular voltage class. It does recommend that intermediate insulation levels be avoided because the steps indicated are now as close together as is practical.

## Impulse Dielectric Strength and Test

An entirely new standard under this title has been proposed. Briefly it requires that transformers shall be able to withstand the following impulse tests with a 1.5x40 microsecond positive wave using the test gap settings given in table 1:

1. A wave not less than 90 per cent of the minimum wave permitted by the test gap.
2. A wave just sufficient to flash over the specified test gap.
3. A wave having a crest at least 10 per cent greater than the minimum flashover voltage of the test gap.

The effective wave front may vary from $^1/_2$ to $2^1/_2$ microseconds, the tail from 40 to 50 microseconds. The test gap is connected directly to ground.

Without the test gap, the transformer shall be able to withstand the following tests:

4. A wave of sufficient magnitude to flashover the bushing. Where oversized bushings are used they should be gapped for this test to the same impulse flashover as the standard bushing for the specified insulation level.
5. A wave as high as in test 3 or 4, but with means for maintaining the excitation voltage across all parts of the winding.

All 5 of these tests are to be made with the transformer under full power voltage excitation[4,5] and with the impulse synchronized within 30 electrical degrees of the 60 cycle voltage crest, on the negative half cycle.

For the foregoing impulse tests standard atmospheric conditions are assumed, namely, an absolute humidity of 6.5 grains per cubic foot and an air

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1. For all numbered references see list at end of paper.

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† Present chairman of A.I.E.E. transformer subcommittee.

density corresponding to a barometric pressure of 760 millimeters of mercury and a temperature of 25 degrees Centigrade. The crest value of the impulse voltage wave should be adjusted to the voltage that would be obtained on the standard test gap under standard humidity and air density conditions. This may be done by making the following corrections to either the gap spacing or the impulse voltage generator setting, the former being preferable: For impulse tests 1 and 2, increase or decrease the gap length or applied voltage 2.5 per cent for each grain the absolute humidity falls below or above 6.5 grains per cubic foot, respectively; for impulse tests 3, 4, and 5, 2.0 per cent. In addition to the correction for humidity, the gap length or applied voltage should be corrected in inverse proportion to the relative air density based upon standard conditions of 760 millimeters of mercury and 25 degrees Centigrade.

The foregoing testing procedure has been in use on large power transformers for 2 years. This experience has demonstrated the practicability of commercial impulse tests.

At the time these testing recommendations were adopted it was thought that they constituted a reasonable demonstration of coördination with the gaps of table I. In view of more recent data on the characteristics of rod gaps at short time lags, it is known that these tests do not demonstrate coördination with the gap at short time lags.[6,7] It appears that they do not always impose as severe a test on the major insulation of the transformer as the present A.I.E.E. low frequency tests. The transformer subcommittee therefore is considering a slight readjustment of the impulse test voltages and the adoption of certain simplifications in the test procedure which experience has demonstrated are desirable. The same general procedure would be employed utilizing the following schedule of tests:

1. A wave just sufficient to flash over the specified test gap directly connected to ground.

2. A wave sufficient to flash over the bushing, provided standard bushings are used, and having a crest voltage bearing a definite relation to the 60 cycle test voltage.

3. A full wave not less than 90 per cent of that required to flash over the bushing, or the test gap, if the bushing is oversized.

The subcommittee has given approval to this revised schedule as the basis for further study and discussion. The value of the multiplier to be used in test 2 is being carefully investigated.

**Table I—Standard Spacing of Insulation Coördination and Impulse Test Gaps**

| Gap Spacing, Inches: Coördination Gap | Gap Spacing, Inches: Test Gap | Rated Circuit Voltage Normally Associated Therewith |
|---|---|---|
| 3/4 | 0.8 | 575 delta, 1,000 star |
| 2 | 2.2 | 2,400 delta, 4,160 star |
| 3 | 3.3 | 4,800 delta, 8,320 star |
| 4 1/8 | 4.5 | 6,900 delta, 12,000 star 13,800 (15,000) |
| 6 1/4 | 6.9 | 23,000 (25,000) |
| 9 1/4 | 10.2 | 34,500 |
| 12 1/4 | 13.5 | 46,000 |
| 18 3/4 | 20.6 | 69,000 |
| 25 | 27.5 | 92,000 |
| 31 1/2 | 34.7 | 115,000 |
| 38 1/4 | 42.1 | 138,000 |
| 44 1/2 | 49.0 | 161,000 |
| 54 1/2 | 60.0 | 196,000 |
| 64 | 70.4 | 230,000 |
| 80 | 88.0 | 287,500 |
| 96 | 105.6 | 345,000 |

**Table II—Recommended Increases in Low Frequency Dielectric Test Voltage**

| Voltage Class | Test Gap Length | Present Test, Kv | New Test, Kv |
|---|---|---|---|
| 23,000 star | 6.9 | 47 | 49 |
| 6,900 delta, 11,950 star; 13,800 star | 4.5 | 28 | 34 |
| 4,800 delta, 8,320 star | 3.3 | 18 1/2 | 26 |
| 2,400 delta, 4,160 star | 2.2 | 10 | 19 |
| 575 delta, 1,000 star | 0.8 | 4 | 10 |

## Revision of Low Frequency Dielectric Tests

Two important changes in the present standards for low frequency dielectric tests have been proposed. The first change would modify those paragraphs (13–400 and –401) dealing with graded-insulation transformers to call for an induced test voltage of 3.46 times normal (double line voltage plus 1,000 volts) which is now common practice. In transformers having reduced insulation the former induced test of 2.73 times normal would be replaced by the test corresponding to the next lower voltage class. This change also would provide for a high potential test on graded-insulation transformers at the test voltage corresponding to the voltage class of the neutral. These suggestions would bring paragraphs 13–400 and –401 of the present standards into accord with actual present-day practice.

The second change would increase the test voltages in the lower voltage classes, 23 kv and lower. It has been known for some years that the present A.I.E.E. tests in the distribution circuit voltages were not consistent with the required impulse strengths. In fact, service experience for years has resulted in a gradual increase in dielectric strength so that transformers are capable of withstanding much more severe tests. Also the proposed impulse tests would require insulation that is able to withstand higher low frequency tests than the present standards call for.

The proposed test voltages can be expressed conveniently by the empirical formula,

Low frequency test voltage = 4.5 kv + (6.5 × length of test gap in inches)

This formula gives the desired increases in test voltage in the lower voltage classes, particularly in the distribution range, as indicated in table II. In voltage classes above 23 kv, it gives test voltages in accord with the present standards.

It was the opinion of the subcommittee that manufacturers should adopt these new test voltages as soon as possible and that users should include them

in specifications so that they may come into general use at an early date.

### Transformer Bushing Flashover Standards

There never has been an A.I.E.E. Standard covering flashover voltages of transformer bushings. With the introduction of impulse testing it seemed highly desirable to establish standard impulse flashover voltages for transformer bushings.

It was thought sufficient to include in the standard only the impulse and wet 60 cycle flashover voltages as these would establish the bushing design since they are the significant requirements. It was also recommended that a common insulation level for bushings be established for both power and distribution transformers at flashover voltages 15 per cent higher than those of the coördination gaps of table I, using gaps, if necessary on power transformer bushings. These suggestions were not altogether satisfactory to the industry. There was a demand for the 60 cycle dry flashover voltages; also it was thought that the 15 per cent level was too low for power transformers in the lower voltage classes.

The subcommittee therefore has decided to recognize the practical fact that power transformers of necessity have larger bushings than distribution transformers and to propose a higher insulation level for bushings on power transformers in the lower voltage classes. The proposed flashover voltages for power transformer bushings are given in table III, which includes values for both 60 cycle dry and wet flashover and impulse flashover. The 15 per cent level is considered satisfactory for distribution transformers, but as yet the actual standard values have not been agreed upon.

In addition to the recommended standard flashover voltages, the subcommittee makes the following proposals to be included in the bushing standard:

#### Mounting for Test.

Bushings shall be mounted in a vertical position in a flat covered tank extending beyond the bushing not less than 25 per cent of the porcelain height. Under conditions of operation, the flashover voltage may be somewhat different.

**Table III—Proposed Power Transformer Bushing Flashover Voltages and Gap Spacings**

| Kv Class | Transf. 60 Cycle Test, Kv | Test Gap, Inches | Equivalent Rod Gap,* Inches | 1.5x40 Microsecond Positive Wave, Kv | 60 Cycle Flashover, Kv Wet | Dry |
|---|---|---|---|---|---|---|
| 4.3 | 19 | 2.2 | 3.4 | 80 | 27 | 40 |
| 8.7 | 26 | 3.3 | 4.5 | 95 | 35 | 50 |
| 13.8** | 34 | 4.5 | 5.75 | 115 | 45 | 65 |
| 23† | 49 | 6.9 | 8.1 | 155 | 60 | 85 |
| 34.5 | 70 | 10.2 | 11.4 | 215 | 85 | 115 |
| 46 | 93 | 13.5 | 15.0 | 270 | 120 | 160 |
| 69 | 139 | 20.6 | 22.3 | 385 | 170 | 225 |
| 92 | 185 | 27.5 | 29.6 | 500 | 215 | 285 |
| 115 | 231 | 34.7 | 36.7 | 600 | 265 | 350 |
| 138 | 277 | 42.1 | 44.0 | 710 | 315 | 415 |
| 161 | 323 | 49.0 | 51.2 | 815 | 365 | 475 |
| 192 | 393 | 60.0 | 62.3 | 980 | 440 | 575 |
| 230 | 461 | 70.4 | 73.0 | 1,135 | 515 | 665 |

* When tested in parallel with bushing gives 50–50 flashover with 1.5x40 microsecond positive wave.
** Includes also the 15 kv class.
† Includes also 25 kv apparatus, but the 60 cycle transformer test is 51 kv.

#### Tolerance.

The tolerance on the 60 cycle bushing flashover voltages shall be within −5 per cent under standard conditions, but the tolerance on impulse flashover voltages has not yet been fully considered by the subcommittee.

#### Standard Conditions.

Temperature: 25 degrees Centigrade.
Atmospheric pressure: 760 millimeters of mercury.
Absolute humidity: $6^1/_2$ grains per cubic foot.
Water resistance and precipitation: 12,000 ohms per centimeter cube with $^1/_{10}$ in. per minute precipitation at a 45 degree angle.

#### Correction Factors.

**1. The resistivity correction factors for wet flashover.**

| Water Resistance, Ohms per Cubic Centimeter | Correction Factor |
|---|---|
| 3,000 | 1.28 |
| 4,000 | 1.19 |
| 5,000 | 1.13 |
| 6,000 | 1.10 |
| 8,000 | 1.04 |
| 10,000 | 1.02 |
| 12,000 | 1.00 |
| 20,000 | 0.99 |

The wet flashover voltage at 12,000 ohm resistivity is obtained by multiplying the measured flashover voltage by the correction factor corresponding to the actual resistivity of the water used in the test.

**2. Air density and humidity correction factor for 60 cycle dry flashover tests.**

For bushings with gaps in voltage classes 23 kv and higher, the measured flashover voltage shall be increased 3 per cent for each grain the absolute humidity falls below standard, and shall be decreased 3 per cent for each grain the absolute humidity exceeds standard.

For all bushings in all voltage classes, in addition to the foregoing correction for humidity, the measured voltage shall be corrected in inverse proportion to the relative air density based upon standard conditions of 760 millimeters of mercury and 25 degrees Centigrade for the range from 90 to 110 per cent of normal density.

**3. Air density and humidity correction factor for impulse flashover tests.**

For bushings with gaps in voltage classes 23 kv and higher, the measured flashover voltage shall be increased $2^1/_2$ per cent for each grain the absolute humidity falls below standard, and shall be decreased $2^1/_2$ per cent for each grain the absolute humidity exceeds standard.

For all bushings in all voltage classes, in addition to the foregoing correction for humidity, the measured voltage should be corrected in inverse proportion to the relative air density based upon standard conditions of 760 millimeters mercury and 25 degrees Centigrade for the range from 90 to 110 per cent of normal density.

It is recognized that the humidity and air density correction factors may have to be changed when more complete data are available.

### Short-Time Overloading of Transformers

It has long been recognized that power transformers of the oil immersed type may be loaded in excess of their ratings under certain conditions. The A.I.E.E. Standard No. 100 at present establishes recommendations for continuous overloads when ambient temperatures are different from those

of the rating standards of section 13. Within the past year the transformer subcommittee has planned to extend the scope of this publication by including recommendations for short-time overloads.

These recommendations have been completed for oil-immersed self-cooled transformers. The considerations upon which they are based and the proposed schedules of overloading were published in the October 1934 issue of ELECTRICAL ENGINEERING,[8] and constructive criticism of the proposal is invited.

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# Loading a Bank of Dissimilar Transformers

**Formulas for determining the unbalance in load of 3 dissimilar single phase transformers operating 3 phase, delta-delta connected.**


By
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SOMETIMES it is necessary to operate 3 dissimilar single-phase transformers in a delta-delta connected bank. These units may have different impedance and voltage ratio or either different impedance or voltage ratio. When operated in this manner it is necessary to know the maximum load that can be carried by the bank. A similar condition exists in case there are several 3-phase banks in parallel and one of the units should fail.


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The object of this article is to present a set of formulas to determine the maximum load that can be taken from this bank of dissimilar transformers, and the unbalance of current and voltage. It is assumed that the primary voltages and the secondary line currents are balanced.

Let

$E_A', E_B', E_C'$ = primary voltage
$E_A, E_B, E_C$ = secondary voltage
$I_a, I_b, I_c$ = line current
$I_A, I_B, I_C$ = winding current

$$N_A, N_B, N_C = \text{turn ratio } \frac{\text{secondary}}{\text{primary}}$$

$$R_A, R_B, R_C = \text{resistance in ohms} = \frac{\%\, IR \text{ drop} \times E^2}{\text{kva} \times 10^5}$$

$$X_A, X_B, X_C = \text{reactance in ohms} = \frac{\%\, IX \text{ drop} \times E^2}{\text{kva} \times 10^5}$$

The resistance and reactance are referred to the secondary side.

$$E_A' = E_B' = E_C'$$
$$\check{E}_B' = \alpha^2 E_A'$$
$$\check{E}_C' = \alpha E_A'$$

$$\alpha = -0.5 + j\,0.866,\ \alpha^2 = -0.5 - j\,0.866$$

The symbol ˇ is used to denote a complex quantity. Voltage $E_A'$ is used as the reference vector.

$$I_a = I_b = I_c$$
$$\check{I}_a = -j\sqrt{3}\, I_A \tag{1}$$
$$\check{I}_b = \alpha^2 \check{I}_a$$
$$\check{I}_c = \alpha \check{I}_a$$
$$\check{I}_A = \check{I}_B + \check{I}_c$$
$$= \check{I}_B + \alpha \check{I}_a \tag{2}$$
$$I_C = \check{I}_B - \check{I}_a \tag{3}$$
$$\check{E}_A = N_A E_A' - \check{I}_A(R_A + j\,X_A) \tag{4}$$
$$= N_A E_A' - (\check{I}_B + \alpha \check{I}_a)(R_A + j\,X_A) \tag{5}$$
$$\check{E}_B = N_B \check{E}_B' - \check{I}_B(R_B + j\,X_B) \tag{6}$$
$$= N_B \alpha^2 E_A' - \check{I}_B(R_B + j\,X_B) \tag{7}$$
$$\check{E}_C = N_C \check{E}_C - \check{I}_C(R_C + j\,X_C) \tag{8}$$
$$= N_C \alpha E_A' - (\check{I}_B - \check{I}_a)(R_C + j\,X_C) \tag{9}$$
$$\check{E}_A + \check{E}_B + \check{E}_C = 0 \tag{10}$$

Substituting eqs 5, 7, and 9 in eq 10 and solving for $\check{I}_B$, we have

$$\check{I}_B = \frac{N_A E_A' + N_B\,\alpha^2 E_A' + N_C\,\alpha E_A' - \alpha \check{I}_a(R_A + jX_A) + \check{I}_a(R_C + jX_C)}{R_A + R_B + R_C + j(X_A + X_B + X_C)} \tag{11}$$

$\check{I}_a$ can be found from eq 1. After $\check{I}_B$ is known $\check{I}_A$ can be found from eq 2 and $\check{I}_C$ from eq 3.

Substitute the currents $\check{I}_A$, $\check{I}_B$, and $\check{I}_C$ in eqs 4, 6, and 8 to find the voltage across the 3 phases. These voltages when substituted in eq 10 should equal zero.

The scalar values of the currents may be calculated from $\check{I}_A$, $\check{I}_B$, and $\check{I}_C$. If any of the currents exceed the values which the corresponding windings can carry without overheating, then the load on the entire bank must be reduced to prevent overloading.

The above formulas assume the load is at 100 per cent power factor. If the load is at some other power factor, the currents should be multiplied by the vector corresponding to it; thus, if the load is at

80-per cent power factor lagging, the factor to multiply the current by would be $0.8 - j\,0.6$.

EXAMPLE

There are 3 1,000-kva transformers available, 2 of which have a voltage ratio of 33,000 volts to 2,300 volts, 0.0328-ohm resistance and 0.2275-ohm reactance. The third unit has a voltage ratio of 33,000 volts tó 2,200 volts, 0.029-ohm resistance and 0.0983-ohm reactance. The load is to be at 80-per cent power factor lagging. What is the maximum load that can be carried and what is the voltage unbalance?

$N_A = 2{,}200/33{,}000 = 0.06666 \qquad N_B = N_C = 2{,}300/33{,}000 = 0.0697$

$R_A = 0.029$ ohm $\qquad X_A = j\,0.0983$ ohm

$R_B = R_C = 0.0328$ ohm $\qquad X_B = X_C = j\,0.2275$ ohm

$\left.\begin{array}{l} I_A = 455 \text{ amp} \\ I_B = I_C = 435 \text{ amp} \end{array}\right\}$ Maximum current winding can carry

$\check{I}_a = -j\sqrt{3}\,(455)\,(0.8 - j\,0.6) = -473 - j\,631$

$$\check{I}_B = \frac{33{,}000\,[0.06666 + 0.0697(-0.5 - j\,0.866) + 0.0697(-0.5 + j\,0.866)]}{2(0.0328 + j\,0.2275) + (0.029 + j\,0.0983)}$$

$$\frac{-(-0.5 + j\,0.866)(-473 - j\,631)(0.029 + j\,0.0983) + (-473 - j\,631)(0.0328 + j\,0.2275)}{2(0.0328 + j\,0.2275) + (0.029 + j\,0.0983)}$$

$$\begin{aligned} &33{,}000\,[0.06666 + 0.0697\,(-0.5 - j\,0.866) + 0.0697\,(-0.5 + j\,0.866)] = -100 + j\,0 \\ &-(-0.5 + j\,0.866)\,(-473 - j\,631)\,(0.029 + j\,0.0983) = -32 - j\,74.16 \\ &+(-473 - j\,631)(0.0328 + j\,0.2275) = \underline{+128.3 - j\,128.4} \\ &\qquad\qquad -3.7 - j\,202.56 \end{aligned}$$

$$2\,(0.0328 + j\,0.2275) + (0.029 + j\,0.0983) = 0.0946 + j\,0.5533$$

$$\check{I}_B = \frac{-3.7 - j\,202.56}{0.0946 + j\,0.5533} = \frac{(-3.7 - j\,202.56)(0.0946 - j\,0.5533)}{(0.0946 + j\,0.5533)(0.0946 - j\,0.5533)} = \frac{-112.6 - j\,17.1}{0.315}$$

$= -357 - j\,54.3 = 361$ amp

$\check{I}_A = (-357 - j\,54.3) + (-0.5 + j\,0.866)(-473 - j\,631) = 426.5 - j\,148.8 = 451$ amp

$\check{I}_C = (-357 - j\,54.3) - (-473 - j\,631) = 116 + j\,577 = 589$ amp

$\check{E}_B{}' = 33{,}000\,(-0.5 - j\,0.866)$; $\check{E}_C{}' = 33{,}000\,(-0.5 + j\,0.866)$

$\check{E}_A = 0.06666 \times 33{,}000 - (426.5 - j\,148.8)(0.029 + j\,0.0983)$
$2{,}200 - 28 - j\,37.6 = 2{,}172 - j\,37.6 = 2{,}175$ volts

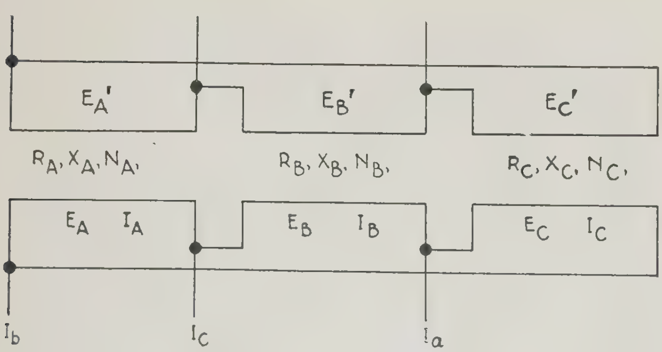
$\check{E}_B = 0.0697 \times 33{,}000\,(-0.5 - j\,0.866) - (-357 - j\,54)(0.0328 + j\,0.2275)$
$= -1{,}150 - j\,1{,}992 - 0.4 + j\,82.9 = -1{,}150.4 - j\,1{,}909.1 = 2{,}230$ volts

$\check{E}_C = 0.0697 \times 33{,}000\,(-0.5 + j\,0.866) - (116 + j\,577)\,(0.0328 + j\,0.2275)$
$= -1{,}150 + j\,1{,}992 + 127.6 - j\,45.3 = -1{,}022.4 + j\,1{,}946.7$
$= 2{,}200$ volts

CHECK:
$$\begin{array}{r} 2{,}172 \quad - j \quad 37.6 \\ -1{,}150.4 - j\,1{,}909.1 \\ \underline{-1{,}022.4 + j\,1{,}946.7} \\ -0{,}000.8 - j\,0{,}000.0 \end{array}$$

Under these conditions transformer $C$ is carrying 136 per cent load. So the load on the bank must be reduced in the ratio $\frac{100}{136}$, or the maximum load the bank will deliver is 2,220 kva.

Assuming the normal line voltage is 2,300, then $E_A = 94.4$ per cent, $E_B = 97$ per cent, and $E_C = 95.6$ per cent. The maximum unbalance is $97 - 94.4 = 2.6$ per cent.




**Three-phase transformer connections, showing symbols used**

# Control of Transients in Welding Generators


**The fundamentals of d-c arc welding generators are reviewed in this paper, and the effect of transient currents and voltages upon performance is described. It is then shown how the transients may be controlled by internal arrangements which reduce the induced voltages in the stator circuit and at the same time increase the series reactance of both the field and armature circuits. A new welding generator designed with these features is next described; it is a modification of the split pole type of self-excited machine. Also, comments on the technique of testing welding generators are presented.**



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SELF-REGULATING generators for use in arc welding, generally known as "single operator welders," differ from conventional d-c machines in 2 main and very important respects. The welding generator is a changing flux instead of a constant flux machine and never operates under steady load. These 2 fundamental differences are so great that new conceptions and new methods of treatment are necessary if the operation and design of welding machines


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are to be understood. Much of the theory of self-regulating generators is well known, but a review of the major points may help to clarify other points and give a better conception of the machine and its operation.

The voltampere curve of a conventional type of d-c generator is shown in curve $A$ of figure 1. The steady state voltampere curve of a welding generator is shown in curve $B$ of figure 1. In the conventional generator the slight droop is caused by resistance and crowding of the flux due to armature reaction. In the welding generator these effects are of minor importance. The drooping characteristic is caused by a definite and major reduction in armature flux. This change in flux may be due to series turns, armature reaction, or other means, and may result in reducing the total flux or in shifting the flux from one circuit to another. The important point is that a large change in armature flux must take place if the drooping curve $B$ is to be obtained.

An arc welding generator under open circuit conditions is primarily the same as a conventional type of generator; the application of load to the machine produces the change in flux necessary to obtain the drooping characteristic. Variations in welding current necessitate changes in flux in the machine. If a change in welding current does not produce a corresponding change in armature flux, then the generator will have the same characteristics as the conventional type of machine.

## I-Fundamentals of Generator Transients

Changing flux always tends to produce voltages which cause currents to flow and these currents oppose the change in flux. Any eddy currents produced in the iron or copper of the machine will tend to prevent the change in flux. If the changing flux threads a field coil, it will produce currents in the field circuit, which also tend to prevent the change in flux. All of these effects retard the flux change, and produce a time lag between the change in welding current and the change in flux. This time lag will cause the generator to operate at some point between the conventional generator steady state curve $A$, figure 1 and the welding generator steady state curve $B$, or on the dynamic curve, shown as curve $C$, figure 1. The greater the time lag between current and flux, the more nearly the slope of the dynamic curve $C$ approaches the slope of the conventional curve $A$, and conversely, the shorter the time lag, the more nearly the slope of the dynamic curve approaches the slope of the steady state curve $B$. If the time lag between current and flux could be eliminated entirely, the generator would operate on the steady state welding curve $B$. The dynamic curve of a welding generator is of the greatest importance, for a welding generator always operates under the transient conditions produced by welding.

The transient currents induced in the iron as eddy currents and in the field circuit as circulating currents arise as the flux initially tries to follow the change in the welding current. These transient currents are dependent upon the rate of change of the welding current and upon the impedance of the circuits. The flux is prevented from changing with the welding current by the presence of these induced currents and, therefore, the time lag between the change in the welding current and the change in flux is dependent upon the magnitude and the rate of decay of the induced currents. In view of these facts it is apparent that any factor which will reduce the rate of change of the welding current or increase the rate of change or reduce the magnitude of the induced currents will decrease the time lag between welding current and flux. This will bring the dynamic curve $C$ nearer to the steady state curve $B$.

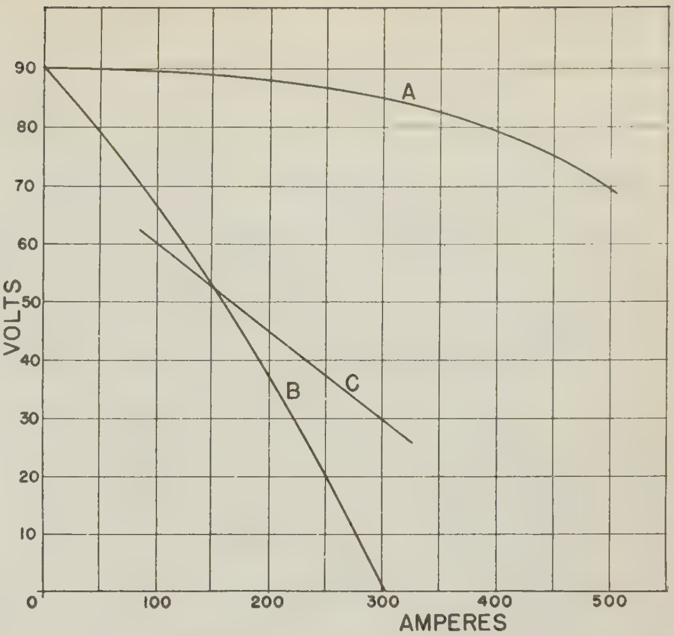


Fig. 1. Operating curves of conventional type and arc welding type of d-c generators

A. Volt-ampere curve of a conventional type of d-c generator
B. Steady-state volt-ampere curve of a welding generator
C. Dynamic volt-ampere curve of a welding generator

The slope of the dynamic curve has a very definite effect upon the operation of a welding generator. The steeper the slope, the more nearly constant the welding current, for in a machine having a very steep dynamic curve, large changes in arc voltage produce small changes in welding current. The steeper the slope the smaller the transient short-circuit current, for this peak current approaches the steady state short-circuit current as the slope increases. A steep dynamic curve denotes small time lag between welding current and flux and results in greater recovery voltage. When the arc is broken, the value of the voltage recovery depends upon the flux in the machine at that instant. Thus, if the flux is able to follow the change in current closely, considerable flux will have been established by the time the arc is broken, with resultant high voltage recovery.

## Reactors and Internal Reactance

The transients in the early type of welding generator were of such a magnitude that good welding could not be obtained. A reactor added to the welding circuit greatly improved the welding char-

acteristics by producing a steadier arc and easier welding and so became standard equipment. The reactor limits current surges during sudden changes in the arc and under short circuit, produces comparatively high transient voltages for maintaining the arc, and reduces the rate of change of welding current. Limiting both the rate of change of welding current and the magnitude of the surge are the most important functions of a reactor. Introduction of the reactor results in a closer approach of the dynamic curve to the steady state curve.

Transformer reactors are an interesting and important step in the improvement of arc welding equipment. In the transformer reactor a secondary winding is connected in series with the field circuit of the welding generator. The relation of primary and secondary is such that the voltage produced in the secondary winding will oppose the voltage induced in the field coils of the machine, thereby partially or fully neutralizing the transient effect in the field circuit. This will materially reduce the transients in the welding generator and produce an effect similar to very large external reactance. It is of interest to note that the necessary reactance in a transformer reactor is much less than in a plain reactor.

A welding generator or any d-c machine has a considerable amount of reactance in the armature, commutating, and series fields. Generally this reactance is not very effective, due to the transient currents flowing in the field circuit and other parts of the generator. If these transients are eliminated or materially reduced, the reactance is released to the welding circuit and the effective reactance becomes much larger. The internal reactance produces

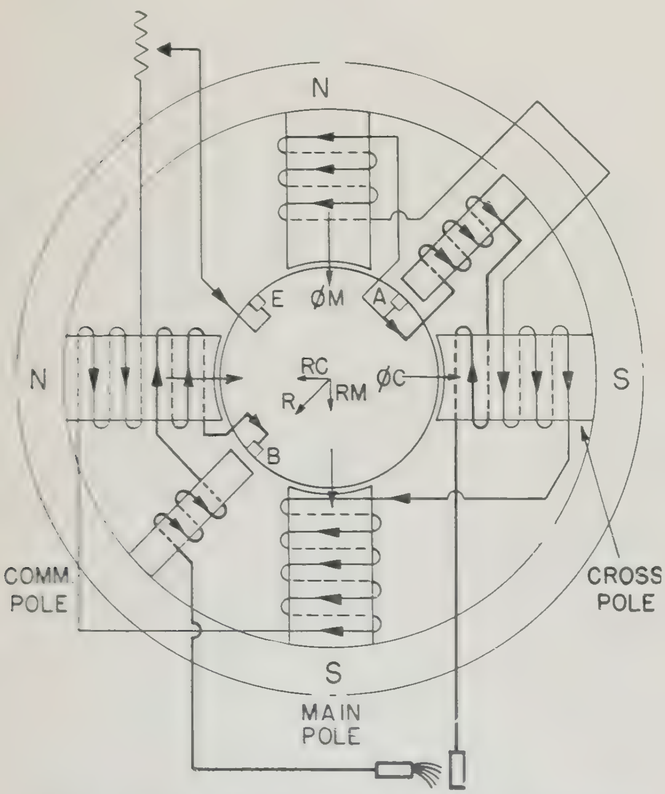


Fig. 2. Schematic diagram of a split pole welding generator having controlled transients

voltage kicks similar to those produced by external reactors. If the reactance of the machine can be utilized, then transient high voltages will be available for maintaining the arc the same as they are when external reactors are used.

Consider the hypothetical case of a welding generator in which there is no time lag between changes in welding current and flux; in this generator, the dynamic curve will be the same as the steady state curve. Due to the steep voltampere curve, a considerable change in the length of the arc could be made without materially affecting the value of the welding current. Voltage recovery would be instantaneous, for by the time the arc is broken, the flux would have returned to the open circuit value. There would be no transient surges or peak values of current on short circuit. Since this machine will have minimum induced currents the inherent reactance of the generator will be effective, and transient high voltages will be produced for maintaining the arc. It is interesting to note that the welding machine inherently without transients, and the welding machine having the transients reduced by external reactors have substantially the same characteristics.

This discussion suggests that it is possible to produce a welding generator having controlled transients without an external reactor. This generator will have all of the characteristics of the conventional type using external reactors or transformer reactors. From the broad point of view this is logical, for if the addition of an external reactor results in satisfactory welding characteristics, then it should be possible to incorporate these characteristics in the generator itself and make the external reactor unnecessary.

## II-A Controlled Transient Welding Generator

The previous sections of the paper have indicated the possibility of designing a welding generator to give excellent characteristics without the use of external reactance. The next few sections of the paper describe how this objective has been accomplished.

Briefly, it has been found possible to incorporate in the design of a split pole welding generator sufficient reactance and freedom from transient excitation changes, to give characteristics fully equivalent to those heretofore obtained by the use of an external reactance. Complete elimination of the transients is economically beyond the scope of commercial machines. Machines using reactors have limited transients and make good welding machines. Therefore, if the transients are reduced so that the same characteristics are obtained without the reactor, the generator will be a good welding machine.

The split pole type of welding generator as designed by S. R. Bergman (see "A New System for D-C Arc Welding," by S. R. Bergman, A.I.E.E. Transactions, volume 50, 1931, page 678–80) offers a simple method of controlling transients. The theory of this machine has been amply covered in the past, therefore a brief résumé of the principle of operation is all that is necessary in this paper.

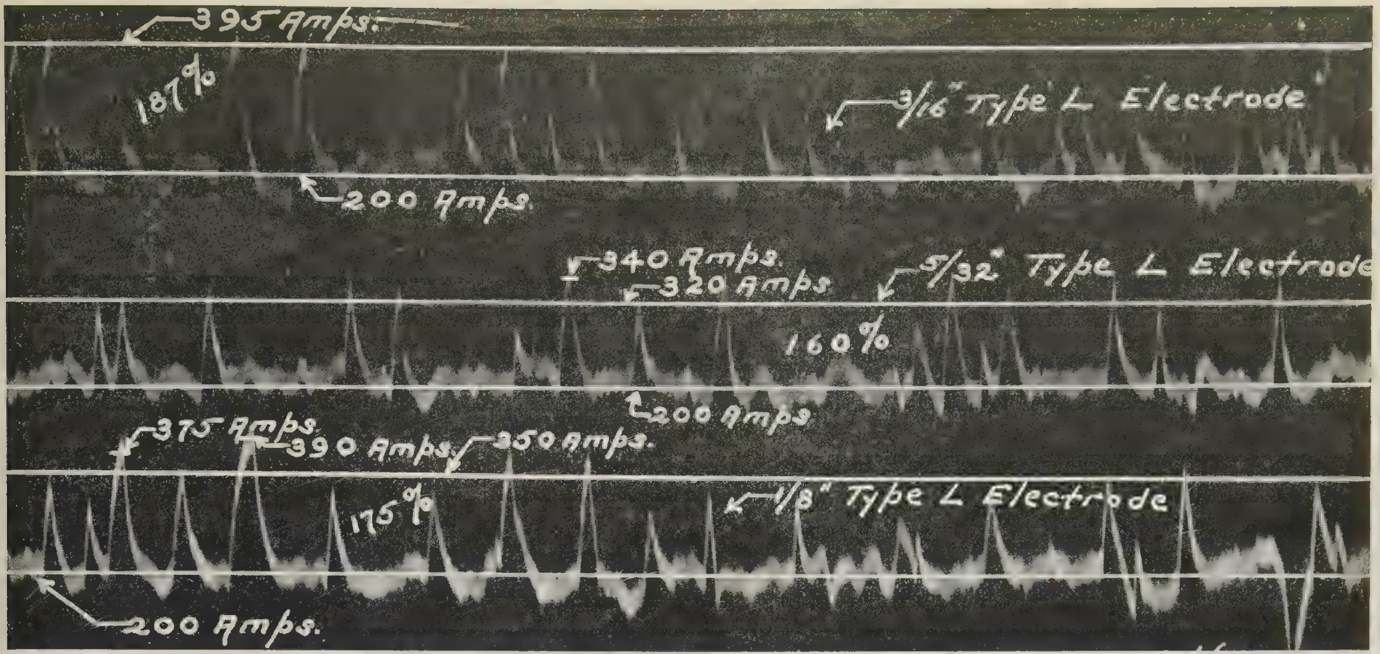


**Fig. 3. Reproduction of oscillogram of welding operation illustrating the effect of changing the size of electrode**
200-ampere 16-volt arc. All conditions constant except for diameter of electrode

### Description of the Generator

The generator is shown schematically in figure 2. The armature is the conventional 2 pole type. The field is divided into 4 poles with adjacent shunt coils connected for the same polarity. This scheme offers 2 distinct flux paths, one through the main poles and one through the cross poles. Shunt fields are connected in series to form a single circuit. Armature reaction and series fields are used to produce current control.

The armature reaction can be resolved into components, one through the main poles and one through the cross poles. The armature reaction in the main poles is in the same direction as the shunt field and will tend to increase the main flux. High saturation in the main pole prevents this increase and holds the flux as nearly constant as is possible with saturation. The armature reaction in the cross poles opposes the shunt field and reduces and finally reverses the flux in the cross pole circuit. Since the line voltage is the algebraic sum of the main and cross voltages, reducing or reversing the cross voltage reduces the line voltage.

### Methods of Eliminating Transients

Transient or eddy currents in the iron are reduced to a minimum by laminating the entire magnetic structure. The transient voltage induced in the field circuit by the changing cross pole flux normally produces the greatest detrimental effect and it is here that the greatest improvement can be made. Since the rise in flux in the main pole is in the opposite direction to the change in the cross pole, the voltages induced in the 2 coils are in opposition. Unfortunately, it is necessary to minimize the rise in main flux.

If the field circuit could be loaded with a reactance the transient current that would flow would be definitely limited. Since it is transient current that causes flux time lag, the limitation of the transient current by a reactance in the field circuit will be quite effective. In the split pole generator the main fields may be used as a loading reactance. In this case, the number of turns in the main field should be as large as possible. Since the 2 fields are in series, a large number of turns on the main field results in high number of ampere turns. This magnetomotive force is consumed by the saturation in the main pole and since this saturated portion was needed to limit the effect of armature reaction, no difficulty is encountered from this point. There is a limit to the number of turns on the main pole, but the possible number is high enough to make the main coil a very good loading coil.

Limiting the duration of the transient field current is just as important as limiting the magnitude. Once the ampere turn ratio between main and cross fields is fixed by design, changing the number of field turns does not appreciably change the ratio between steady state field current and transient field current. Changing the number of field turns will change the time constant of the field circuit and the duration of the transient current. If the number of turns in the fields is reduced, the duration of the transient is reduced and its effect on the welding circuit is limited.

### Internal Reactance

The reactance of a split pole machine is higher than the reactance of a conventional generator. The split pole generator has reactance in the armature due to leakage flux in the pole face and around the slots, the same as a conventional machine. In addition to these conventional sources of reactance, the cross pole circuit offers a definite path for reactance flux. This flux flows through the pole, magnetic frame, and back through the opposite

cross pole. This flux threads the cross coils, but since transient currents in the field circuit are minimized, the flux is free to move and the reactance is very effective. Transient currents in iron or field reduce the usual leakage reactance and the reduction of these transients increases the effectiveness of armature and leakage reactance as well as making available the reactance due to the cross flux. Moreover, in a split pole generator the series turns are concentrated on 2 of the 4 poles. This requires twice the number of series turns as used in a differentially wound machine and gives the split pole machine twice the series turn reactance.

In conclusion, the controlled transient generator is of the split pole type with a completely laminated magnetic structure. The number of turns in the cross field coils is small and these are connected in series with the main coils having a large number of turns. The result is a generator in which the time lag between current and flux is reduced to a minimum and the effective reactance increased so that the machine has characteristics similar to one with an external reactor.

## III-Testing Welding Generators

One of the most difficult problems confronting the designer is the determination of the characteristics of a welding generator. There are a number of well-known tests, but these do not give a definite means of evaluating the welding machine. This is to be expected since definite agreement on the desirable characteristics of welding generators, backed by conclusive test and theory, has not been reached.

The final criterion of a machine is its operation under actual welding conditions. In order to obtain a true evaluation of a welding machine it is necessary to operate the set for a considerable length of time under various welding conditions, for it is very difficult to obtain true results from short-time welding tests. It takes considerable time for the operator to get the feel of the set and the condition of the weld specimens materially affect the operator's views. Perhaps the greatest single factor against a short-time welding test is the operator himself. Unless specially trained for testing, operators will unconsciously evaluate a set in terms of the welding generators they have been operating, and this is usually true irrespective of the quality of their regular machines. It has also been found that welders who attended their welding school only a few years previously will invariably favor a welding machine similar to the machine on which they learned to weld. Of course, considerable progress can be made in evaluating a generator by means of so-called blindfold tests, wherein the operator works with a number of electrodes without knowing the sets to which they are connected and attempts to pick out the generator which he considers the best welding machine. In any case, the short-time welding test leaves much to the imagination and the results have to be used with the greatest of care.

Oscillograms of actual welding are of doubtful value, due to the extreme difficulty of controlling the conditions under which the oscillograms are taken. Practically any kind of oscillogram may be produced by the proper selection of wire, work, and operator. An example of the variations that may be obtained in oscillographs by minor changes in conditions is shown in figure 3. This oscillograph was taken under carefully controlled conditions: an expert welding operator made the test after considerable practice, the temperature of the machine was constant, the type of wire was the same in each case, each weld was made on a cold plate of the same thickness and composition, and the length of arc and value of current were the same. The weld at the bottom was made with $^1/_8$ inch, the middle with $^5/_{32}$ inch and the top with $^3/_{16}$ inch electrode. The difference in results is obvious and illustrates that extreme care must be used in taking oscillographs of welding. Changes in type of electrode, temperature of parts, speed of weld, or any other condition materially affects the results.

Steady state tests are naturally easy to obtain and are reliable. While the value of regulation, efficiency, saturation, and other steady state tests is unquestioned, these tests do not give an evaluation of the machine as a welding generator.

Short-circuit tests are not actual conditions encountered in welding but they can be carefully controlled and give a good method of testing for transients. From this test, oscillograph measurements of the short-circuit surge current give a very good criterion of the transients in the machine. The reverse of the short-circuit test, or the voltage recovery test, made by placing the machine under short circuit and then suddenly opening the circuit, is also subject to close control of the conditions, and again gives a very good criterion of the transients, as well as the voltage kick.

Effective reactance tests made by applying alternating current to the terminals of the welding generator have little value unless the results can be compared directly with other machines of similar type. Under these conditions, the reactance value gives a very good comparison between the effective reactance of the sets. Since it is quite difficult to test with currents high enough to produce saturation, the reactance value obtained is useful only when compared with similar types of tests.

Considering the various methods of testing, it becomes evident that still further and more reliable methods are highly desirable. It is very likely that a better understanding of the desirable welding characteristics will, in turn, produce better methods of testing and evaluating welding generators.

The results presented in this paper show that a very wide range of generator characteristics can be obtained by design and circuit changes, and that it is quite possible to incorporate within the generator itself all of the features required to obtain welding characteristics in conformance with accepted requirements. However, there is considerable disagreement in regard to relations between the welding generator characteristics and the production of good welding so that it is desirable to conduct further research to determine more accurately the characteristics which should be incorporated in an ideal welding generator.

# Measurement of Noise From Power Transformers

**From the results of an investigation on a typical large electric power system, it is concluded that the specification of tolerable noise in transformers by means of measurements with commercially available noise meters is entirely practicable. The problems involved in this investigation and the principal results obtained are presented and discussed in this paper.**

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MEMBER A.I.E.E.

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FOR SEVERAL YEARS the residents in the vicinity of transformer substations have been becoming increasingly noise-conscious. As a result, the need for quiet transformers for service on electric power systems has been growing constantly. In attempting to satisfy this need, however, both the manufacturer and the purchaser have been handicapped by the lack of any suitable standards for the tolerable amount of noise. In most cases, the purchaser could determine the permissible degree of noise by reference to existing installations of similar nature, but to state those requirements in definite terms that would be interpreted correctly by all concerned was well-nigh impossible. During the past 2 years, The Detroit Edison Company has been investigating the feasibility of using noise meter measurements as a dependable and definite means of specifying transformer noise.

From the results of this investigation to date, as presented in detail in this paper, it is concluded that the specification of tolerable noise in transformers by means of measurements with commercially available noise meters is entirely practicable. In fact, sufficient information is now available for 2 ratings of transformers to warrant the inclusion of actual values for permissible noise in future purchase specifications issued by this company, and similar values will be available shortly for other ratings. This paper will be limited to an explanation of the method, together with a presentation of the supporting experimental data, with no attempt to recommend values to be used in actual specifications as such values depend too much upon the judgment of the purchaser and the service for which the transformer is intended.

Full text of a paper recommended for publication by the A.I.E.E. committees on electrical machinery and power transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 1, 1934; released for publication Oct. 18, 1934. *Not published in pamphlet form.*

### Measuring Equipment and Unit of Measurement

The type of noise meter used was that which measures the pressure level of the total noise with inherent compensation for the equivalent loudness of the component notes according to a predetermined weighting curve. Measurements were made with commercially available noise meters, one manufactured by the Westinghouse Electric and Manufacturing Company and one by the General Electric Company. Since both meters have been described previously in the technical press, no detailed description is needed here. (See "An Electrical Ear," by K. A. Oplinger, *The Electric Journal,* August 1931; "The Measurement of Machinery Noise," by H. B. Marvin, A.I.E.E. Transactions, volume 50, 1931, pages 1048–51.) It is sufficient to state that this type of meter consists essentially of a microphone placed at the point at which the noise is to be measured, and the amplifying, weighting, and measuring equipment necessary to convert the output of the microphone to a reading on a properly calibrated milliammeter.

The unit in which the pressure level is expressed throughout this paper is the decibel, which is defined according to the latest proposed standards of the American Standards Association by the formula $db = 20 \log \frac{p}{0.0002}$, where $p$ is the acoustic pressure of the sound wave in dynes per square centimeter. It should be noted that the reference pressure used, 0.0002 dynes per square centimeter, corresponds to a reference intensity of $10^{-16}$ watts per square centimeter as specified in the proposed standards. As a rough guide for those not familiar with this unit of measurement, it might be stated that a transformer having a total noise of 50 decibels could barely be heard 300 feet away on a quiet night while a transformer having a total noise of 70 decibels could be heard easily at twice that distance. For the range of values in this paper, a change in total noise of less than 0.5 to 1.0 decibel probably would not be noticed by the average listener.

### Summary of Conclusions

Although the investigation as originally planned has not been entirely completed, sufficient information has been obtained to warrant definite conclusions on that phase of the problem dealing with the development of a method to be used in the specification of noise. Based upon the results of more than 2,500 separate noise meter measurements on about 60 transformers in actual service at 20 city and suburban substations, the following conclusions are drawn:

1. The tolerable noise in a transformer can be specified satisfactorily as the average total noise for at least 25 microphone positions located according to the general plan shown in figure 1. The transformer must be so located that the meter reads inherent noise unaffected by external conditions. The make of the noise meter to be used in the measurements must be stated.

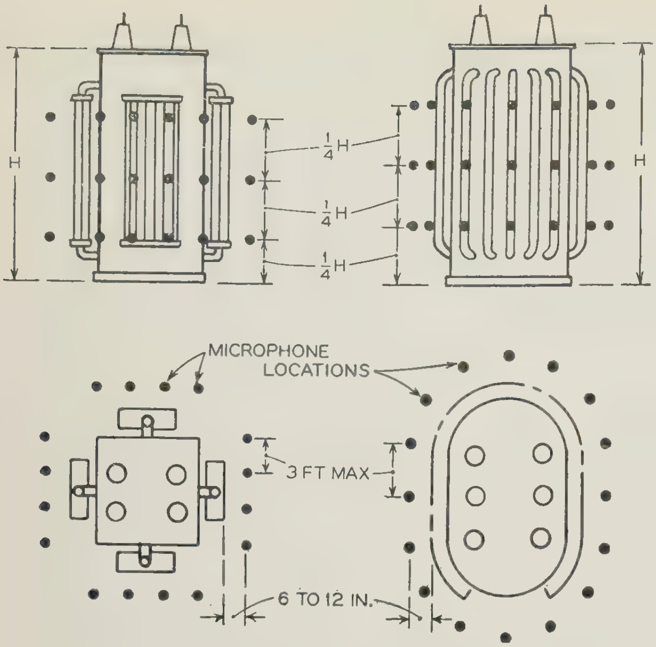



**Fig. 1. Typical positions of microphone for use in measuring total noise for specification of tolerable noise in transformers**

2. At the present time, noise meters of different makes do not give the same results, even when compensation for dissimilar weighting networks is included. In the 2 meters compared, a difference of at least 8 decibels was found. To facilitate the general acceptance of noise specifications, some standard of reference should be established against which different meters can be calibrated. Preferably, the manufacturers of noise meters should include similar weighting networks and calibrate their instruments for equal readings. Obviously, this should not be difficult as the difference is not due to fundamental differences in the design of the meters. It is to be hoped that the subcommittee of the American Standards Association that is now working on the development of meter standards and calibration methods, together with the manufacturers of noise meters, will be able to solve this problem in the near future.

3. So long as the same meter, or probably a meter of the same make, is used, the results of measurements of the total noise of transformers taken under conditions readily obtained in practice can be depended upon for purposes of comparison if the method suggested in the first conclusion is followed. On the average, measurements could be repeated the same day within 0.5 decibel. Using the average of 8 repeated measurements over a period of $2^1/_2$ months as the reference, individual measurements during this period averaged within 1.0 decibel of this reference. The maximum differences were about double these values, 1.2 and 2.1 decibels, respectively.

4. The results of noise meter measurements clearly differentiate between quiet units and others. Individual transformers measured within about 3 decibels of the average for each group of duplicate units, while the difference between the average noise for transformers considered quiet and the average for any other group was about 8 to 10 decibels.

## General Plan of the Investigation

Until a few years ago, the measurement of noise was a highly specialized problem requiring trained experimenters with delicate equipment which could hardly be used outside the laboratory. With the introduction of modern noise measuring equipment, however, noise measurement no longer was reserved for the research scientist, but became a useful tool in the solution of practical noise problems. It seemed reasonable, therefore, that measurements with a noise meter could be used to specify permissible noise in transformers. It was obvious that the result for a single position of the microphone was not adequate because of the nonuniform character of the sound pattern around the transformer. Not only does a slight change in the position of the microphone sometimes change the reading on the meter by several decibels, but also the noise at one point is not a true indication of the noise from the complete transformer. It seemed probable, however, that the average of measurements of total noise for a series of microphone positions forming an envelope around the transformer as shown in figure 1 might be a true criterion of the acceptability of a transformer. Before such a method of noise specification could be accepted, experience had to be accumulated to answer 3 questions:

1. Can such an average value be checked on repeated measurements on a given transformer under practical conditions of measurement?

2. Are the values obtained on different transformers about the same for transformers considered about equal in noise characteristics, and, for transformers considered unequal, is there sufficient difference to insure proper discrimination?

3. Are the requirements as to extraneous noise and the relative positions of surrounding reflecting surfaces so stringent as to make such measurements prohibitive?

Considered theoretically, there were many reasons why all the questions might be answered in the negative. For instance, since noise meters were somewhat untried, there was some doubt about their accuracy when used under the practical conditions of field testing. It was evident even to a casual observer that the readings were affected by such factors as air movement against the diaphragm of the microphone, mechanical vibration of the microphone support, temperature of the instrument, and extraneous magnetic fields. Furthermore, it was not certain that the inherent noise of the transformer bore a

**Table I—Comparison of Repeated Measurements of Total Noise With the Same Meter**

| Group / Date of Test | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | Average Total Noise in Decibels | | | | | |
| June 19 | 61.6 | 58.6 | 58.8 | 58.6 | 55.9 | 55.7 |
| June 19 | 60.8 | 58.2 | 59.8 | 58.0 | 54.7 | 54.8 |
| June 20 | 59.3 | 56.5 | 58.5 | 57.0 | 53.9 | 52.9 |
| June 20 | 59.3 | 57.1 | 58.1 | 56.6 | 53.9 | 52.8 |
| Aug. 21 | 59.8 | 58.0 | 58.0 | 55.8 | 54.1 | 52.7 |
| Aug. 21 | 59.7 | 57.8 | 57.8 | 56.1 | 53.8 | 52.3 |
| Sept. 5 | 58.4 | 56.8 | 56.7 | 55.2 | | |
| Sept. 5 | 60.3 | 59.3 | 58.3 | 57.1 | 55.5 | 54.1 |
| Average | 59.9 | 57.8 | 58.3 | 56.8 | 54.5 | 53.6 |
| **Difference Between Measurements Taken on Same Day** | | | | | | |
| June 19 | 0.8 | 0.4 | 1.0 | 0.6 | 1.2 | 0.9 |
| June 20 | 0.0 | 0.6 | 0.4 | 0.4 | 0.0 | 0.1 |
| Aug. 21 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 |
| Average | 0.3 | 0.4 | 0.5 | 0.4 | 0.5 | 0.5 |
| Sept. 5 | 1.9 | 2.5 | 1.6 | 1.9 | | |
| **Difference Between Each Result and the Average** | | | | | | |
| June 19 | 1.7 | 0.8 | 0.5 | 1.8 | 1.4 | 2.1 |
| June 19 | 0.9 | 0.4 | 1.5 | 1.2 | 0.2 | 1.2 |
| June 20 | 0.6 | 1.3 | 0.2 | 0.2 | 0.6 | 0.7 |
| June 20 | 0.6 | 0.7 | 0.2 | 0.2 | 0.6 | 0.8 |
| Aug. 21 | 0.1 | 0.2 | 0.3 | 1.0 | 0.4 | 0.9 |
| Aug. 21 | 0.2 | 0.0 | 0.5 | 0.7 | 0.7 | 1.3 |
| Sept. 5 | 1.5 | 1.0 | 1.6 | 1.6 | | |
| Sept. 5 | 0.4 | 1.5 | 0.0 | 0.3 | 1.0 | 0.5 |
| Average | 0.75 | 0.74 | 0.60 | 0.87 | 0.70 | 1.07 |

direct relationship to its design and type of construction, or that it remained constant from day to day even with the same load and voltage. Again, there was no complete data to indicate the magnitude of the effect on the measured noise of the extraneous noise level and the relative character and position of surrounding reflecting surfaces. As in all noise problems of a complicated nature, the simplest and most positive method to obtain information on these factors was by experiment. In this case, it seemed best to check their combined effect by taking a comprehensive series of measurements in the field on transformers in actual service under a range of conditions, using men regularly employed for such test work to make the measurements. Such an experiment would indicate whether laboratory accuracy in the control of extraneous conditions or the constant supervision of highly trained experimenters was necessary to obtain reasonably accurate results. If so, such a method would not be accepted generally by the electric power industry and must be discarded in favor of some more practicable scheme.

The general plan of the investigation to answer the 3 questions stated may be outlined by grouping the measurements according to their purposes:

1. The first group was made to determine the consistency of repeated measurements for 3 conditions: with the same meter, with different meters of the same make, and with meters of different makes. In all tests, measurements of total noise were made for a given set of microphone positions around a given transformer. This procedure was repeated on the same transformer several times under such different extraneous conditions as prevail during actual operation, and the results were compared.

2. The second group was made to indicate the comparison between the measured results and the noise characteristics of a transformer. Representative readings of total noise were taken on a large number of different transformers and the average results were compared. The classification of transformers according to these results then was checked against the opinions of listeners as to the noise characteristics of these same units.

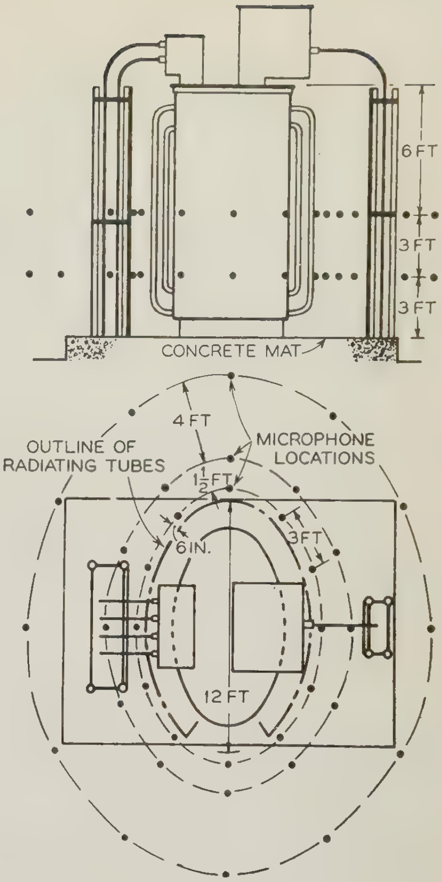
3. The third group, which was not complete at the time this paper was written, is intended to show the effects of extraneous noise and surrounding reflecting surfaces. To do this, the total noise of a given transformer will be measured with these factors varied, and the results will be compared.

## Consistency of Repeated Measurements

The first group of measurements may be subdivided further, as suggested, to show results with the same meter, with different meters of the same make, and with meters of different makes.

*Results With the Same Meter.* To determine the comparison using the same meter, a 6,000 kva transformer installation was selected at a substation in a well-developed residential district close to a heavily traveled highway. Using the same meter, a reading of total noise was taken at each of the microphone positions shown in figure 2 several times during a period of $2^1/_2$ months. Each time, the readings for the 12 microphone positions equally distant from the transformer and at the same height were combined to obtain the 6 groups of average values tabulated in table I according to the date of measurement. The readings for the same day were taken from 1 to 3 hours apart. No changes were made in the meter during this period except that the

**Fig. 2. Positions of microphone for checking consistency of measurements on 6,000-kva 3-phase transformers**




batteries were renewed between the 2 readings taken on September 5. The differences between comparable results of measurements taken within a few hours of each other, as shown in the center of the table, show a maximum difference for this condition of measurement of 1.2 decibels with an average of less than 0.5 decibel for the first 3 days. The comparison for September 5 shows that an average difference of about 2.0 decibels may be expected between readings with new batteries and those at the minimum values set by the manufacturer. The comparison of the 8 readings taken over the $2^1/_2$ month period shows a greater difference than those taken the same day, as would be expected because of the possibility for wider variation in external conditions. Since the average of the 8 results for each group tends to be the correct value, the difference between any reading and this average is a measure of the accuracy to be expected in repeated measurements. As indicated in the tabulation at the end of table I, the maximum difference obtained was 2.1 decibels and the average of all these differences was less than 1.0 decibel.

In view of the fact that an average listener would have considerable difficulty in differentiating between 2 transformers 1.0 decibel different in total noise, even by comparing them directly, it is believed that the accuracy of this check is well within that required for practical measurements. It should be remembered, moreover, that some of these readings were taken at night under quiet conditions while others were taken during periods of heavy traffic, that the transformer was in regular service so that its load and voltage varied to some extent, that the

noise meter was not calibrated at the laboratory during that period, that different operators were used to read the meter, that the battery voltage in the meter varied over the complete range considered allowable by the manufacturer, that the meter was transported by automobile at least 2,500 miles during that period, and that weather conditions were not constant, although all readings were taken in the late summer. It is believed that with more careful control of some of these factors, particularly meter battery voltage, transformer load and voltage, and extraneous noise, even closer checks could be obtained.

*Results With Meters of the Same Make.* The measurements to determine the comparison between different meters of the same make were not so conclusive because 2 such meters were not available. During the period of test, however, one of the meters was sent back to the factory for minor changes and recalibration. When it was returned, the correction factors and calibration curves were all different so that it corresponded to a different meter of the same make. Several groups of readings were made on 6,000 kva transformers before recalibration and repeated after the meter was returned. The average results for each group, tabulated in table II, show a maximum difference of 2.4 decibels with an average for the 6 groups of 1.3 decibels. Inasmuch as these comparative measurements were taken from 6 to 18 months apart, this close check is considered reasonable proof that similar meters made by the same company can be used for obtaining comparative values for purposes of noise specification.

*Results With Meters of Different Makes.* Measurements made to check the difference between results obtained with 2 meters of different makes fall into 2 classes. For the first class, measurements were made on 2 different banks of 1,000-kva single-phase transformers with microphone positions as shown in figure

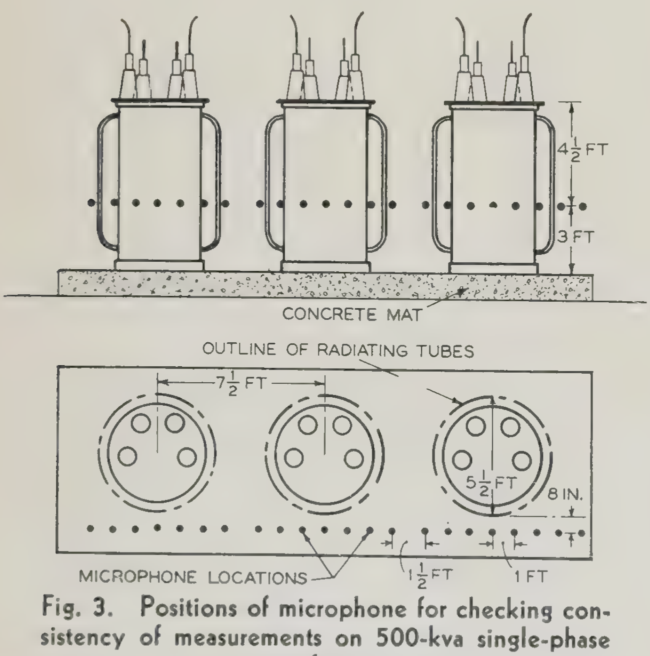



**Fig. 3. Positions of microphone for checking consistency of measurements on 500-kva single-phase transformers**

**Table II—Comparison of Repeated Measurements of Total Noise With One Noise Meter Before and After Factory Recalibration**

| Group | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Before recalibration, db | 60.9 | 57.4 | 61.1 | 59.3 | 62.1 | 58.4 |
| After recalibration, db | 60.1 | 57.9 | 62.1 | 61.2 | 63.1 | 60.8 |
| Difference | 0.8 | 0.5 | 1.0 | 1.9 | 1.0 | 2.4 |
| Average difference | | | | | | 1.3 decibels |

**Table III—Comparison of Repeated Measurements of Total Noise With 2 Noise Meters of Different Makes**

| Group | 1 | 2 | Avg. | 3 | 4 | 5 | 6 | 7 | | Avg |
|---|---|---|---|---|---|---|---|---|---|---|
| Meter *A*, db | 64.0 | 62.8 | | 62.3 | 59.7 | 59.6 | 66.0 | 64.4 | 62.8 | |
| Meter *B*, db | 60.3 | 58.0 | | 56.3 | 54.2 | 54.2 | 60.9 | 57.4 | 57.8 | |
| Difference* | 3.7 | 4.8 | 4.2 | 6.0 | 5.5 | 5.4 | 5.1 | 7.0 | 5.0 | 5.8 |

* Correction for weighting network adds about 4.0 decibels to these values.

3. Readings for all positions of the microphone were made with one meter, and immediately thereafter repeated with the other meter. Not more than 15 minutes elapsed between readings with different meters, so there was little chance for conditions to change. For the second class of measurements, readings were taken on 2 6,000-kva 3-phase transformers with microphone positions similar to the 6 inch groups in figure 2, with additional readings at a height of 9 feet. In these tests, however, several days elapsed between the measurements with one meter and those with the other. As indicated by the maximum difference of 2.1 decibels in the results obtained under similar conditions when the same meter was used, any greater difference than this can rightfully be charged to dissimilarity between the meters. The first 2 columns of table III give the results of this comparison for the first class of measurements and the remaining 6 columns give the results for the second class. As indicated, an average difference between meter readings of 4.2 decibels was obtained for the readings taken practically simultaneously, and 5.8 decibels for those taken on different days. Unfortunately, these 2 meters were not designed for equal weighting of the component notes. Since the dissimilar results might be accounted for on this basis, correction should be made for this factor. Applying this correction on the basis of the analysis of total noise which was made at the time the total noise was measured, it was found that the correction of about 4.0 decibels added to the difference already found making the corrected difference between meter readings at least 8.0 decibels.

From this series of measurements, it may be concluded that measurements of total noise with a noise meter of this type, taken under practical conditions of measurement can be relied upon for purposes of comparison so long as the same meter is used, and probably so long as meters of the same make are used. Measurements with meters of different makes, however, cannot be compared directly unless the proper correction is obtained and applied. Until such time as the industry establishes a standard reference against which different meters can be cali-

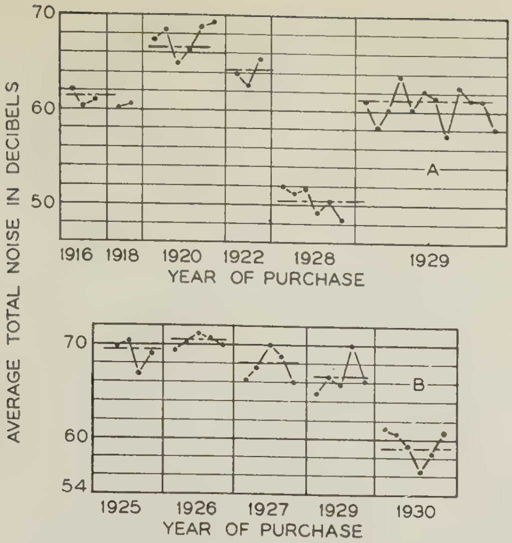



**Fig. 4. Average total noise from transformers in service on The Detroit Edison Company system**

A. 500-kva 24,000/4,800-volt single-phase transformers
B. 6,000-kva 24,000/4,800-volt 3-phase transformers
—·—Average for group

brated, or the manufacturers of noise meters recalibrate their meters to read alike, it will be necessary to indicate the make of meter in specifying noise.

### Correspondence Between Meter Readings and Transformer Noise

As previously stated, the second series of readings was taken to determine whether the result of such a total-noise measurement is a proper criterion of the acceptability of a transformer from the standpoint of noise. According to the procedure previously outlined, measurements of total noise were made on 57 transformers which had been in actual service from 5 to 18 years. This number included 2 ratings, 500-kva single-phase, and 6,000-kva 3-phase, some purchased as duplicate units, and some obviously different as to construction of tank and inherent design. It was apparent that the noise characteristics varied over a wide range; some units, particularly in the smaller rating, were so noisy that they would not be considered acceptable today, and others were about as quiet as any that have been built for these ratings.

The average results of total-noise measurements on all these transformers are plotted according to the year of purchase in figure 4. The dots connected by the solid lines are the values for units purchased at the same time as duplicates. It is quite probable that some of the units purchased at different times may be essentially duplicates as far as all factors affecting noise are concerned; this point was not checked, however, because of insufficient information regarding the design of the transformers.

An analysis of the values plotted in figure 4 clearly shows a correspondence between the design of a unit and its measured total noise. For units of duplicate design, which were built according to the same design specifications and under the same manufacturing conditions but with no special emphasis on their noise characteristics, the maximum difference between the value for any unit and the average for the group was 3 decibels. However, the difference between the average values for transformers that were obviously different in design was at least 8 decibels. This indicates that once the fundamental factors causing noise in transformers are determined, it should be possible to build quiet transformers consistently according to a given design. Furthermore, assuming that only transformers of the lowest group for each rating were considered acceptable, there would be no difficulty in differentiating between those units and the rest of the transformers tested, depending solely on the results of total noise measurements.

There still may be some question, however, as to whether the classification of these transformers according to noise meter measurements corresponds to a similar classification by ear, which, after all, is the basis upon which a unit is judged after installation. The transformers covered by these measurements were in actual service at different stations so that it was impossible to judge the comparative noise by listening alternately to one transformer after another. It is exceedingly difficult to differentiate by ear between transformers that do not differ greatly in noise characteristics when those units are several miles apart. In this case, however, there was sufficient difference to permit dividing the transformers roughly into 3 groups, those considered quiet, those considered normal, and those definitely noisy. Of the 500 kva transformers, there was no doubt that the units purchased in 1928 were very quiet, and those purchased in 1920 were exceptionally noisy; the ones purchased in 1916, 1918, and 1929 were somewhere between these 2 extremes, and were considered about normal for this class of transformer. Of the 6,000 kva transformers, there were no exceptionally noisy units and the only ones that appeared other than normal were those purchased in 1930. These were definitely quieter than any others of the same rating on the system. From this correspondence between the logical classification of these transformers by meter measurements and the rough grouping according to the opinions of listeners, it seems safe to conclude that the results of total-noise measurements on such meters can be depended upon in purchasing transformers according to noise specifications.

It is of interest to note that the 500 kva units that measured about 70 decibels were considered noisy, while the 6,000 kva units that measured about the same were considered normal. This is probably because it is customary to expect less noise from smaller units, and indicates that different values for acceptable noise probably should be used for different sizes of transformers. It is interesting to note also that the 500 kva units purchased in 1916 and 1918 are practically equal in noise to those purchased in 1929. Apparently during that period, there was no pronounced trend toward quieter transformers.

### Effect of Extraneous Conditions

The information so far obtained is believed to furnish reasonable proof that it is practicable to

specify the inherent noise of a transformer, provided only that the unit under test is so located that the measurements are not seriously affected by extraneous noise and by the proximity of major reflecting surfaces. In any specification for transformer noise, definite requirements as to these 2 factors should be included. It is the present plan to continue this investigation to obtain more comprehensive data on the effects of these factors. From the limited information now available, the requirements do not appear to be particularly stringent so long as the transformer can be located outdoors for measurement. Apparently, any open space corresponding in size and noise conditions to an average lot in the residential section of a large city probably would be suitable, particularly if the readings were taken at night. Whether or not such measurements could be made inside the manufacturer's factory buildings without serious error is problematical. It is believed that additional investigation will show that this is entirely possible, although the measurements may have to be made at night. At any rate, the difficulties of such measurements are not insurmountable and some solution can be found with a little study.

### Analysis of Transformer Noise

It may be contended that an analysis of the transformer noise into its component notes, as well as the total noise, should be used for specification purposes. At the start of this investigation, it was thought that it might be necessary to specify the maximum value for the largest component note, but now it appears that in the majority of cases, the specification of total noise will be sufficient. However, in view of the fact that there may be a few instances where the values of the component notes are important, several analyses of transformer noise already have been made and more will be made as time permits.

Admittedly there are still several factors in the general problem of specifying noise in transformers that remain to be studied, but it seems that sufficient data have been collected to prove that the method of specifying noise outlined in this paper is satisfactory. In view of the increasing interest in noise being displayed by the general public, the noise of a transformer has become an important factor which must be considered in purchasing such equipment. Therefore in any future purchase specifications on major transformers issued by The Detroit Edison Company, it is intended that some such specification will be included. Other electric power companies confronted with this same problem have, no doubt, their own ideas on methods of noise specification. It is hoped that as such information is presented, these companies will find it possible to specify transformer noise using, of course, values for permissible noise suitable to their own requirements. Only by actual experience with such promising methods can the present confusion be removed and eventual standards of noise specification be evolved that can be accepted by all concerned.

# Cathode Ray Tubes and Their Application

**Several distinctive types of cathode ray tubes are described in this paper, starting with a brief description of the Braun type and followed by more detailed descriptions of recently developed types. The characteristics, the selection for a given application, and the operation of sealed-off gas-focused types and of high vacuum types are discussed. Also auxiliary apparatus is considered; and applications of cathode ray tubes are suggested briefly.**

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FOR many years, the cathode ray tube has been known to possess unique properties making it indispensable for certain research investigations. Although its usefulness and versatility were recognized at an early date, the cathode ray tube has not acquired extensive use in the fields of applied engineering. This slow utilization by engineers of a device having such excellent theoretical possibilities has undoubtedly been due in part to the lack of rugged, reliable, low cost, and readily available tubes.

Today, cathode ray tubes have reached a state of development such that the user can depend upon them for information previously obtainable only by more costly and more delicate apparatus. A cathode ray tube operated at relatively low voltages shows a clear, sharp trace in a well-lighted room and is readily calibrated so that quantitative measurements can be made. It is easily applied to a wide variety of practical engineering uses.

The principle on which the cathode ray tube operates is illustrated by figures 1 to 5. These show schematically the essential elements of certain distinctive types of cathode ray tubes. It will be seen that all of these have the following attributes: A containing envelope $E$ of either glass or metal for the purpose of maintaining in the tube either a low pressure of gas or a vacuum; a cathode $C$ for the production of free electrons; an anode $A$ for accelerating the electrons; a method for concentrating the electrons into a beam by means of apertures $O$,

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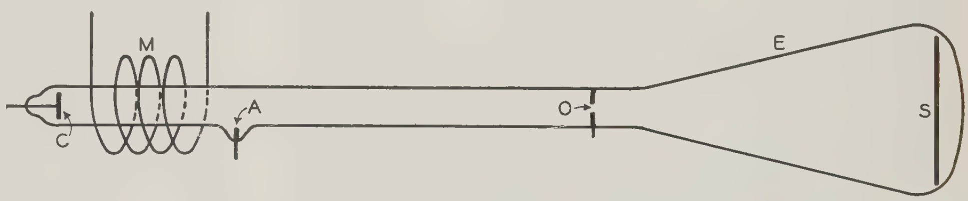
or through focusing fields applied by means of electrodes $F$, or by externally mounted electromagnets $M$, or by a combination of these. The electrons are concentrated into a beam and focused to a point on a screen $S$ made of a material which will show a fluorescent glow at the point of impact by the electron beam. Since the electron beam consists of rapidly moving electrons, it constitutes a current having both electromagnetic and electrostatic properties, but without the mass ordinarily accompanying a conductor of current. Hence, the electron beam can be deflected easily and rapidly by electromagnetic and electrostatic fields. The deflecting fields produced by the phenomenon under investigation take the form either of electrostatic fields usually produced by voltages applied across the deflecting plates, illustrated by $D$ in some of the figures, or electromagnetic fields usually produced by current in coils illustrated by $T$ in figure 5. The deflected electron beam traces on the screen a fluorescent path which can be viewed, measured, and photographed.

## Types of Tubes

Brief descriptions of several distinctive types of cathode ray tubes follow.

*The Braun Type.* The Braun type of cathode ray tube, illustrated in figure 1, is enclosed in a glass bulb about 50 centimeters in length. A small metal disk, the cathode, is mounted at the end of the bulb neck. The anode is a small metal rod projecting into the bulb from the side. Beyond the anode is a diaphragm separating the cathode-anode section from the deflecting field and the fluorescent screen section. The diaphragm has a centrally located aperture of about one millimeter in diameter. The gas pressure in the tube ranges from 4 to 8 microns of mercury. A voltage of 12,000 to 30,000 volts is usually applied between anode and cathode. When the tube is in operation, the ionized gas molecules bombard the cathode plate causing impact emission of electrons which are accelerated by the high positive potential toward the anode. Because the anode is small and on one side of the bulb, many of the electrons travel on past it through the aperture in the diaphragm. This constitutes the cathode ray or electron beam which is deflected by electric or magnetic fields and produces the fluorescent pattern on the screen at the enlarged end of the tube. A magnetic solenoid is sometimes placed concentrically over the small end of the tube to assist in focusing the electron beam on the screen.

**Fig. 1. The Braun cathode ray tube**




*The Dufour Type.* The Dufour type, shown diagrammatically in figure 3, usually employs a cold cathode source of electrons similar to that of the Braun type but also provides for inserting photographic plates or film inside of the tube. The screen end of the tube is usually made of metal with a removable compartment for holding the photographic plates. A vacuum pump and pressure gauge are part of the operating equipment. About 12 minutes are needed to produce the required vacuum which in one type is equivalent to a pressure of 10 microns for a potential of 50,000 to 60,000 volts between cathode and anode. The electrons record by acting directly on the photographic emulsion. A good trace is recorded even when the electron stream sweeps across the film as rapidly as 100 miles per second. The Dufour type, due to the high recording speeds attainable, has proved most useful for the investigation of very high speed transient phenomena. However, the elaborate equipment and its high cost have limited the use of this type.

*The Lenard Type.* The Lenard type is similar to the Braun type except that the former has a window of some thin material, usually metal foil or glass, on the screen end of the tube. Since the window must withstand atmospheric pressure, it requires support and is limited in size by practical considerations. The photographic plate for recording high speed transient phenomena is located outside the tube close to the window section. The electron beam is accelerated with about 75,000 volts. As a result of the high velocity of the electrons, the beam passes through the window and is recorded directly on the photographic plate. The difficulties of producing a satisfactory window which will not unduly limit the sweep of the electron beam have prevented extensive practical use of this type.

*The Wehnelt Type.* The Wehnelt type using an oxide-coated thermionic cathode as the source of electrons was suggested by Wehnelt shortly after the advent of the Braun type. Figure 2 illustrates schematically a tube of this type. It is inherently a low voltage type, since the electrons are released at the cathode by an oxide-coated thermionic emitter in the presence of gas. Due to the effect produced on the cathode by the gas present in this type, the operating life is limited to a few hours.

*The Low-Voltage Gas-Focused Type.* The low-voltage gas-focused type is in some respects like the Wehnelt type. An oxide-coated thermionic cathode is used but the tube is sealed off with a definite gas pressure. The electron beam is produced by a tubular anode mounted at the end of a protecting shield located around the filamentary cathode. Anode voltages from 250 to 400 volts can be used. The anode current is approximately 0.5 milliampere. The adjustment of the focus of the electron beam is

controlled by the filament current. D-c filament supply must be used. The pattern on the fluorescent screen is viewed best in subdued light. Recurrent wave forms may be photographed by focusing an ordinary camera on the fluorescent pattern on the screen. By careful operation of the filament at the lowest current which will focus the electron beam to a suitable fluorescent spot, the life of this type is extended appreciably beyond that of the earlier Wehnelt type. The low-voltage gas-focused type is useful for recurrent wave forms where low voltage operation is desired.

*The Medium-Voltage Gas-Focused Type.* The medium-voltage gas-focused type is shown in figure 4. It operates with anode voltages from 400 volts to 2,500 volts. The cathode consists of an oxide coating applied to a small section at the tip of the filament. The filament is operated at a voltage less than one volt in order to permit a-c operation. The filament current is controlled by means of a rheostat with an ammeter in series and is kept at the lowest value consistent with a sharply focused spot on the screen. A Wehnelt-cylinder electrode around the cathode is operated at a negative voltage to control the beam focus and reduce the positive ion bombardment of the cathode. The tube is sealed off at a gas pressure corresponding to the operating conditions and the dimensions of the tube. The higher operating voltages of this type improve the brilliancy of the fluorescent pattern. As a result, the viewing and photographing properties are enhanced. Better life is obtained than in the earlier types. This type is now used extensively in Europe and has been used to some extent in this country.

*The High Vacuum Type.* The high vacuum type is illustrated in figure 5. This type has been brought to a high state of development in this country. It operates on principles similar to those of the high-vacuum amplifier tube. The focusing of the electron beam on the fluorescent screen is accomplished by means of electrostatic fields produced by the electrodes in the tube. In order to control the brilliancy of the fluorescent pattern, a control electrode is introduced. The beam current is controlled independently of focusing and of beam acceleration. This permits a definite control of the brilliancy of the fluorescent pattern. An indirectly heated cathode is used in this type so that it can be operated on a-c voltage. Rated filament voltage is supplied by a transformer. This type is like usual receiving tubes, not especially critical to line voltage fluctuations.

The electrodes constituting the electron gun are: Cathode, control electrode, accelerating electrode, focusing electrode (anode 1), and high voltage electrode (anode 2). The accelerating electrode is omitted in some types. Beyond anode 2 is the deflecting plate system or a narrow section of the bulb across which may be mounted electromagnetic deflecting coils. The fluorescent screen material is coated directly on the inner surface of the large end of the bulb. A conductive coating is sometimes applied to the inner surfaces of the sides of the bulb. The coating is conductively connected to the anode terminal and provides a well-defined anode potential free from the influence of stray charges over the entire region between the electron gun and the fluorescent screen. In some cases, the anode terminal is mounted on the side of the bulb. This arrangement provides spacing for the use of high voltages on the anode.

High vacuum type tubes for operation at anode voltages from 600 volts to 10,000 volts are available. Operation much below 1,000 volts does not, in general, give as sharp a focus as does the low-voltage gas-focused type. A brilliant and well defined trace on the fluorescent screen of a high vacuum type is obtained with an anode voltage of 1,000 volts. Inherently, there is no limitation to the range of anode voltages, either low or high, over which high vacuum tubes can be made to operate.

Since the life of the high vacuum tube depends

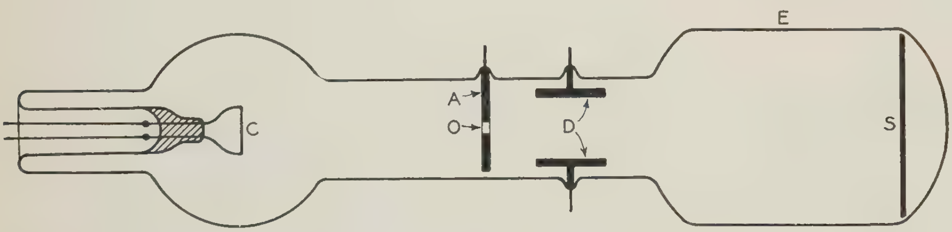



**Fig. 2 (above). The Wehnelt cathode ray tube**

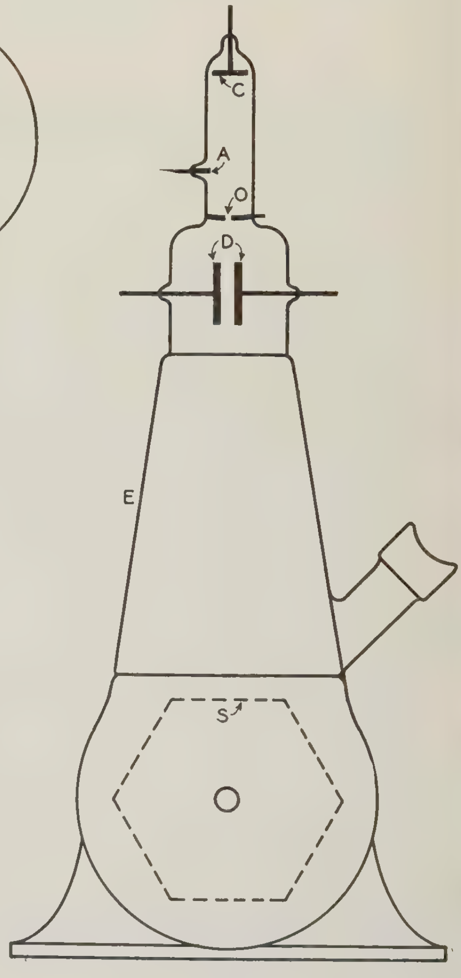
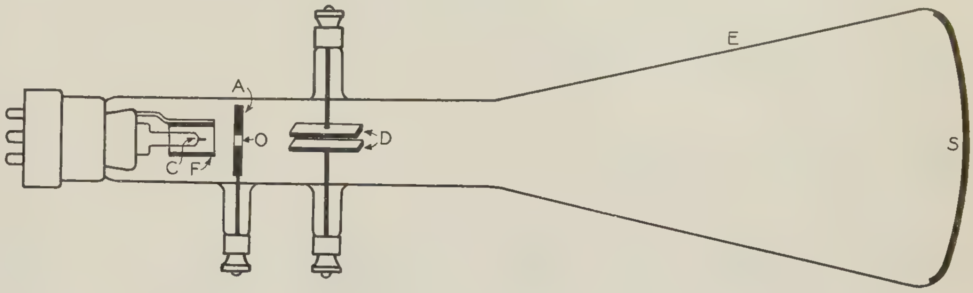



**Fig. 3 (right). The Dufour cathode ray tube**

upon the same factors that determine the life of high-vacuum amplifier tubes, the same operating life can be expected. The screen is generally very stable so that only excessive electron bombardment or heating impairs its usefulness. Inherently, therefore, the life of the high vacuum type should be good. Practically, results confirm this statement.

The improved cathode ray tubes now available are useful not only for viewing and recording recurrent wave forms, as were the earlier low voltage types, but can be used over a greater range of transient phenomena. For example, velocities of the fluorescent spot of 16 miles per second have been recorded with an ordinary camera and a high-vacuum cathode-ray tube operating at 10,000 volts.

Fig. 4. The gas-focused cathode-ray tube




### Factors Influencing the Selection of a Cathode Ray Tube for a Given Application

Some of the characteristics influencing the choice of a cathode ray tube type for a certain application are as follows:

*The Effect of Anode Voltage.* Below 1,000 volts on the anode, the deflection sensitivity of the cathode ray tube is high; however, the luminous brilliancy of the pattern is low. The focus is liable to be poor, although in some tubes, particularly of the gas-filled low-voltage type, it is fairly good. The deflection of the beam is more easily influenced by stray fields, and distortion of the pattern is more likely to occur than at higher voltages.

Voltages ranging from 1,000 volts to 2,000 volts produce a sharply focused spot and well defined line. The pattern is clearly visible in a normally lighted room. Periodic phenomena can be viewed, traced, and photographed satisfactorily. When a nonrecurrent phenomenon is photographed, the velocity of the spot on the screen must be low enough to give sufficient illumination to record. The effect of stray fields on the movement of the beam can usually be eliminated by proper location and shielding of the tube.

Anode voltages ranging from 2,000 volts to 10,000 volts contribute toward a sharply focused spot and greater luminous brilliancy. This voltage range is useful in recording transient phenomena. The high voltage decreases the deflection sensitivity so that the deflecting voltage or current must be increased.

Anode voltages ranging from 10,000 volts to 75,000 volts have been used extensively in the Braun tube and later in the Dufour and similar types of tubes for the recording of lightning surges and other high speed transient phenomena. The complete pattern in some instances is traced in from 1 to 10 microseconds.

*Means of Deflecting Beam.* One arrangement for deflection of the beam consists of 4 electrostatic deflection plates with the terminals connected through the tube base. Two of the plates may have a common connection. This type is useful in many applications where an inexpensive and compact tube is required. The deflector plate capacitance of this design is low enough and the impedance high enough for most applications.

Another arrangement has 4 electrostatic deflection plates with separate terminals mounted on the sides of the bulb. The separate terminals permit a greater latitude in circuit connections. A mid-point ground connection can be used to secure a balanced impedance to ground. The capacitance between the deflector plates is low. The deflector plate impedance for this design can be made higher than with the design where connections are made through the base.

An arrangement with one pair of electrostatic deflection plates with the terminals on the side of the bulb is useful when magnetic deflection can be used on one axis or when deflection in only one direction is to be used, as in recording on moving film. The use of combined electrostatic and electromagnetic deflection is of advantage when it is necessary to reduce interaction of the 2 deflecting fields to a minimum.

An arrangement without electrostatic deflection plates obtains deflection entirely by magnetic fields from externally mounted coils. Where electromagnets can be used, this method permits obtaining a considerable range in sensitivities by the design of suitable coils.

*Choice of Size of Viewing Screen.* A large sized screen permits showing a large pattern and good detail. In general, the accuracy of measurements may be increased by the use of a large screen, but often a large pattern may be examined "piece by piece" on a smaller-sized screen with the aid of biasing voltages. A large screen requires greater deflection voltage to utilize the full screen. The large sized screen also means an increase in the over-all dimensions of the equipment assembly. A tube with a medium or small sized screen requires less space and can be used conveniently in portable equipment. Less deflecting voltage is needed than

for larger screens. Accuracy corresponding to good engineering practice is obtained readily with moderate sized tubes.

*Effects of Properties of Luminescent Screens.* An efficient screen is one giving a high luminous brilliancy for a given wattage input per unit of screen area. Since the power that can be dissipated per unit area of the screen is limited by heating or disintegrating of the screen material and by local heating of the glass bulb, there is a definite limit to increasing brilliancy by increasing anode voltage and beam current. Also, as the beam current is increased, the size of the spot on the screen tends to become larger. It is evident then that a screen delivering high candlepower per watt input can, for example, record higher-speed transients than a similar screen with a lower efficiency.

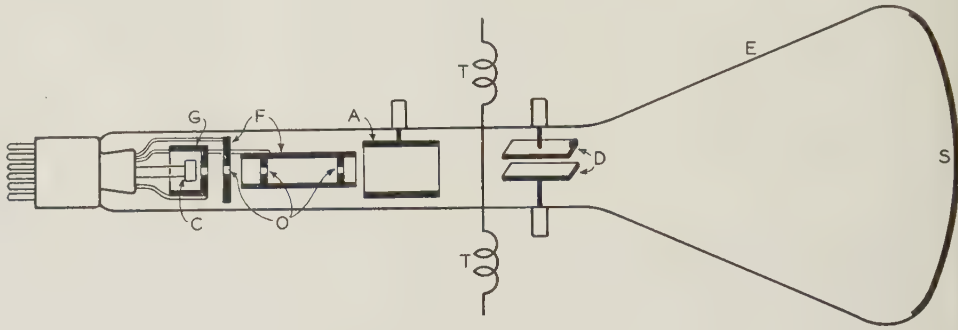
The persistence characteristic of the screen shows the brilliancy of the phosphorescent after-glow as a function of time relative to the initially excited fluorescent glow. A medium or long persistence screen aids in viewing transient phenomena. The trace on a long persistence screen may be seen for several seconds when viewed in subdued light. A short persistence screen is useful for recording on moving film where the time in which the relative brilliancy falls to a low value determines the speed at which the film can be operated without causing blurring of the trace on the film.

The spectral characteristic of the screen shows the radiant energy versus wave length or the color distribution of the excited fluorescence. A green-colored light corresponds most nearly to the maximum sensitivity of the eye; a blue light corresponds to maximum photographic effect on ordinary blue-sensitive and verichrome emulsions. The green color in addition to its good viewing properties may have sufficient spectral energy in the blue region to be good for verichrome emulsion and gives additional photographic sensitivity when supersensitive panchromatic film and plates are used.

*Effect of Conductive Coating on Bulb.* A conductive coating on the inner surface of the bulb is effective in bringing the anode potential close to the screen. This produces greater freedom from stray fields, better ability to respond to high speed transient phenomena when the beam current is switched on and off rapidly, and less current pick-up by the deflector plates. For example, when a very high deflector-plate resistance is desired, a tube with inner coating and separately mounted deflector terminals on the bulb should be used. Conductive coating is sometimes applied to the outer surface of the bulb to serve as an electrostatic shield.

*Means of Focus and Brilliancy Control.* The adjustment of focus and brilliancy of the trace on the screen may be made by separate controls such as are used on typical high vacuum types, or these adjustments may be limited to the control of focusing with the brilliancy being determined by the anode voltage. The latter arrangement is commonly used in the Wehnelt-cylinder gas-focused type. The use of a separate brilliancy control permits an increase above normal for short periods while photographic records are being made. It also permits the use of low voltages to control the beam current.

**Fig. 5. The high-vacuum cathode-ray tube**




*High Vacuum and Gas Types of Cathode Ray Tubes.* The high vacuum type is independent of frequency from zero up to high radio frequencies where the electron velocity due to deflecting fields approaches the electron velocity due to anode voltages.

The gas type is independent of frequency until the deflection velocity becomes great enough to interfere with the ionization of the gas by the electrons in the beam. Since the focusing depends upon the ionization of the gas along the path of the beam, the focus becomes poor at high radio frequencies.

The deflector plate resistance is in general lower for the gas type than for the high vacuum type. This is especially noticeable for small deflecting voltages, or when the source of driving power is limited. The deflector plate resistance of the high vacuum type depends upon the electron current collected by the deflector plates. This can be made as low as desired by reducing the beam current or by the use of a tube with an internally coated bulb.

When tubes are operated at anode voltages below 1,000 volts, sharper focus is generally obtained with gas type tubes designed for low voltage.

In general, there is less background light on the screen in a high vacuum than in a gas type.

The operating life of the gas type may be limited by cathode bombardment or change in gas pressure. The life of the high vacuum type is inherently good.

*Effects of Deflector Plate Capacitance and Impedance.* A deflector plate capacitance of a few micro-microfarads and a deflector plate resistance in excess of a megohm will have a negligible effect when connected to most circuits. When the circuit requires

low capacitance, the spacing and mounting of the deflector plates should be considered. The deflector plate resistance in a high vacuum type may be increased by the use of lower beam current. However, brilliancy of the pattern need not be sacrificed if higher anode voltage is available. An internal coating on the bulb also increases deflector plate resistance of the high vacuum type.

*Linearity of Deflection.* Distortionless electromagnetic deflection requires a uniform distribution of magnetic field across the path of the beam. The stray magnetic field should not concentrate in the focusing region. With this method of deflection control, it is advantageous to use a tube having provision for properly located and closely spaced electromagnets. With correctly designed tubes using electrostatic control, the deflection is linear with voltage.

*Response to High Speed Transient Phenomena.* The high-speed transient response of the gas focused type is determined by the time required for ionization, which is of the order of $10^{-6}$ seconds.

When the high vacuum type is used for viewing or recording high speed transients, where the beam current is switched rapidly on and off, a momentary accumulation of charge may occur on parts of the bulb before sufficient time to obtain equilibrium has been reached. The use of a tube with an internally coated bulb eliminates the possibility of any such difficulty.

There is no inherent time or frequency limitation in the case of the high vacuum type, although with conventional tubes, at frequencies of about $10^8$ cycles per second or a wave length of about 3 meters, a limitation begins to appear due to the finite velocity of the electrons. This limitation also exists in other types of high vacuum tubes; the limiting frequency being determined by the physical dimensions of the tube and the accelerating voltage.

### Installation and Operation of the Gas Focused Type

The hot-cathode gas-focused cathode-ray tube can be compared with a gas filled detector tube. As in the case of other gas filled tubes, particular care should be taken to see that rated voltages are never exceeded. It is essential to long filament life that the tube should be used at the lowest filament voltage and lowest anode voltage which will give a sharp focus and sufficient brilliancy on the fluorescent screen for the particular application. It is always advisable to use a meter to show the filament current and to have the filament current continuously adjustable between the maximum rated value and approximately $^1/_2$ this value.

Some of these types can be operated on d-c filament voltage only. Other types may be operated with a-c filament supply. The a-c types usually operate with less than one volt on the filament to avoid the effects of a-c ripple. The filament current should be adjustable and kept as low as consistent with obtaining a sharply focused spot. The filament current may be lowered slightly after the tube has heated. During the life of the tube, a gradual increase in filament current is usually required to produce a sharp spot on the screen. The focusing voltage on the Wehnelt-cylinder electrode is kept as negative as possible consistent with a sharply focused spot. The brilliancy of the pattern may be increased by using higher anode voltage, but the maximum rated anode voltage should not be exceeded. In general, the 3 operating parameters of the tube are anode voltage, filament current, and Wehnelt-cylinder voltage. For a fixed value of one of these, there may be several combinations of the other 2 which will give an approximately focused spot. Generally, the first 2 should be kept at as low a positive voltage as possible and the latter, as negative as possible.

It is advisable to shield the tube from the influence of stray electric and magnetic fields. The stray fields from transformers, chokes, and auxiliary apparatus may be avoided by a suitable disposition, spacing, and orientation of parts. Likewise, stray fields from equipment external to the cathode ray apparatus can be minimized.

### Installation and Operation of the High Vacuum Type

The high vacuum cathode-ray tube is in many respects like a high vacuum amplifier tube. No special technique is required in installing and operating the tube other than that normally used in the handling of high vacuum amplifier tubes. The cathode is indirectly heated, like an a-c amplifier tube, from the winding of a transformer and is operated at rated voltage without any adjustments. The currents to the electrodes of the electron gun usually total 0.1 or 0.2 milliampere or less so that the current in the voltage divider may be as low as about one milliampere. Under these conditions, the ripple in the rectified voltage is small and a condenser of 0.5 to 2.0 microfarads supplies adequate filtering. The d-c power required is low so that a small transformer with proper insulation for the high voltage can be used. A few one watt carbon resistors and potentiometers serve as the voltage divider. A half-wave rectifier or a voltage-doubler rectifier circuit is suitable. The rectified d-c voltage is approximately equal to the peak of the a-c voltage for the half-wave circuit or twice this value for the voltage doubler circuit. The rectifier tube carries only a small current but must withstand a peak inverse voltage of twice the peak a-c voltage of the transformer.

The control electrode is normally operated with a bias voltage negative with respect to the cathode. It is used for controlling the beam current and hence the brilliancy of the fluorescent pattern. Usually, the control electrode voltage is made adjustable by means of a potentiometer tap in the voltage divider in order to permit a range of voltage from zero to a voltage sufficiently negative to cut off the beam current completely.

When the tube has an accelerating electrode, it is normally connected to a fixed tap on the voltage divider corresponding to rated voltage.

The focusing electrode (anode 1) is used to focus

the beam current to a sharply defined spot on the screen. The voltage of this electrode is usually equal to approximately $^1/_5$ of the voltage on anode 2. A range of adjustment upward to about $^1/_3$ of the voltage on anode 2 is usually allowed.

When the brilliancy of the fluorescent pattern is adjusted, considerable defocusing sometimes results due to the regulation of the high-resistance voltage divider. This is readily corrected by adjusting the focusing voltage, or it may be eliminated, if desired, by increasing the current in the voltage divider.

If a range of anode voltages is required, a potentiometer on the line voltage side of the high voltage transformer will change the voltage on all electrodes simultaneously. This method will keep the pattern approximately in focus. Proper location or shielding of the tube is advisable in order to avoid the influence of stray electric and magnetic fields.

### Sweep Circuits and Auxiliary Apparatus

In order that the wave form of phenomena producing a vertical deflection may be viewed, a horizontal deflection is applied to sweep across the screen at a uniform rate. The linear time sweep may traverse the screen only once when observing a nonrecurrent wave form or it may be arranged to be returned rapidly to its starting position and to repeat the linear time sweep.

When the frequency of the wave form being observed is a multiple of the repetition frequency of the linear time sweep, the wave form remains stationary on the screen. The number of cycles of the wave form appearing throughout the sweep on the screen shows the ratio of the frequency of the wave form to the frequency of the linear sweep voltage. Thus, a sweep frequency of 3,000 cycles per second shows 4 cycles of a 12,000 cycles per second wave form.

A linear time-sweep generator with good linearity, short-return sweep time, good frequency stability, and adjustable in frequency from very low frequencies to the upper audio frequency range, is available with present tubes. The type *RCA-885* gas filled triode tube was especially designed for this service. With suitable circuits, a sweep of 200 volts amplitude (or by special arrangements, 400 volts amplitude) can be obtained. The linear time sweep is generated by charging a condenser at a constant current rate. The constant current characteristic of the plate circuit of a pentode amplifier tube is used preferably as the constant-current controlling device. A diode operated at low filament voltage to produce saturation may also be used for this purpose. Another means consists in using only a small portion of the initial charging curve of the condenser. Since the exponential charging characteristic of a condenser is initially linear, the use of a high resistance in series with the condenser and a high charging voltage will permit an appreciable amount of voltage across the condenser before it departs appreciably from linearity. Either the charging or the discharging voltage of the condenser may be arranged to produce the linear time sweep. The return sweep occurs on discharge or charge according to the circuit arrangement. The time constant of the circuit causing the return sweep should be low with respect to the time of the sweep. Generally, the arrangement is used in which the condenser charging produces the linear time sweep and the discharge the return sweep. Any one of these methods properly employed is capable of a high degree of linearity.

The return sweep occurring on the discharge of the condenser may be accomplished electrically by a gas filled triode or in certain applications it may be done mechanically by a rotating contact, a tuning fork, or other means. The gas filled triode permits a large frequency range and locked synchronization with the wave form being observed. Synchronization is locked by means of a small amount of wave form voltage coupled to the grid circuit of the gas filled triode. The mechanical method either controls the phenomena being observed and is, therefore, self-synchronized, or it provides a standard with which the frequency of the wave form can be compared.

Other time bases are used for various applications. A 60 cycle per second wave of approximately sine-shape voltage from the power line is often useful as a sweep voltage. When the amplitude is made large enough to cause the end portions to sweep beyond the limits of the screen, the central portion is nearly linear. If the frequency of the wave form being observed is a multiple of 60 cycles per second, the wave form will appear stationary on the screen and will have an approximately linear time distribution. Since the sweep and the return sweep of the 60 cycle per second voltage are the same, the wave form is spread twice across the screen. One method for preventing confusion of the wave form pattern consists in applying some of the 60 cycle per second voltage with a 90 degree phase shift to the deflection in the vertical direction. The result is that the sweep and the return sweep appear as 2 separate lines on the screen, since the 60 cycle per second voltages sweep out an elongated ellipse instead of a line. Another method consists in making the return sweep invisible by applying some of the 60 cycles per second voltage with a 90 degree phase shift to the brilliancy control electrode. The beam current is cut off during the return sweep by the negative half of the 60 cycles per second voltage. Where exact linearity is not necessary, this 60-cycle sweep method is convenient. Since there are a large number of 60 cycle intervals over the audio frequency range, a stationary wave form is readily obtained. The wave forms of different frequencies can be spread to convenient proportions by increasing the 60 cycles per second sweep voltage within the limits permissible in the deflecting circuits of the cathode ray tube.

A circular time base is often useful for frequency comparisons. In general, an ellipse results with axes parallel to the deflecting directions when voltages of the same frequency but with a 90 degree phase relation are applied to the deflecting plates. When the deflection amplitudes in the 2 directions are equal, the ellipse becomes a circle. The voltage with a 90 degree phase relation is readily obtained by means of a condenser and resistance. If the voltage source supplying the circular time base is changed

rapidly from zero to a maximum, the successive circles produced by each cycle are swept into a spiral. The spiral affords a convenient time sweep of known variable velocity and of considerable length on the screen.

Other auxiliary apparatus used frequently are amplifiers and current transformers. Resistance coupled amplifiers are most useful when uniform response over a wide frequency range is needed. For extremely low frequencies and d-c voltages, directly coupled amplifiers are used. For high frequencies where a wide range is needed, resistance coupled amplifiers having screen grid or pentode tubes and low plate-load resistances are used. The resistance coupled amplifier is used to amplify voltages to the proper level for applying them to electrostatic deflecting plates or electromagnetic deflecting coils. If a low resistance is introduced into a circuit where current is to be observed, a small voltage drop in the resistance is produced which may be amplified to a level suitable for deflecting the cathode ray beam.

Current transformers provide a means for converting current into voltage suitable for direct connection to the electrostatic deflection plates. When a uniform response over a frequency range is desired, the primary of the current transformer is connected across a low resistance in the circuit in which the current to be observed flows. The inductance of the primary is made high so that its reactance in the frequency range used will be large with respect to the resistance. The voltage developed across the primary is stepped up by the turn ratio of the transformer, the secondary of which is connected to the deflection plates. For example, with a turn ratio of 100 to 1 and the primary shunted with 10 ohms, a current of 10 milliamperes will produce 10 volts on the secondary or a peak-to-peak amplitude of about 0.5 inch on the screen of a cathode ray tube operated at 1,000 volts.

## Applications of Cathode Ray Tubes

It is impractical in a discussion of this length to more than hint at some of the possible applications for cathode ray tubes. Fundamentally, the cathode ray tube may be regarded as an electron pointer or the movement of an uncalibrated electrical indicating device. The calibrating scales and circuit are provided by the user to suit his particular type of measuring or indicating apparatus.

One of the simplest uses of the cathode ray tube is the measurement of voltage. This is most conveniently done with the electrostatic deflection type of tube. The displacement of the spot on the screen is directly proportional to the applied voltage. When a d-c voltage is applied, the polarity as well as the magnitude is indicated by the displacement of the spot. When an alternating voltage is applied, the spot sweeps back and forth with an amplitude proportional to the peak-to-peak value of the applied voltage. For example, a 10-volt root-mean-square sine wave produces a sweep with an amplitude equal to 28 volts. At frequencies above 8 cycles per second, the sweep of the spot appears as a line, due to the persistence of vision. There is no error due to frequency until extremely high radio frequencies are reached. Overvoltage on the deflecting plates, which is not excessive, merely sweeps the spot off the screen. Thus, the cathode ray tube, being rugged, having a high impedance, and being independent of frequency, is useful as a peak voltmeter.

Since the electron beam can respond to several deflecting fields simultaneously or in rapid succession, the cathode ray tube can be used for time or frequency comparisons. The feature of being able to combine in the cathode ray tube the effects of 2 or even more factors makes it possible to obtain graphical results directly on the screen; as, for example, the tracing of the hysteresis characteristics of samples of iron and the tracing of resonance characteristics of tuned circuits. The inertialess characteristic of the electron beam makes it particularly applicable for high frequencies, although it responds equally to all frequencies usually encountered. It is, therefore, well suited for the viewing and recording of transient phenomena. Wave form is shown when the deflection is spread with a linear time-sweep voltage. A direct indication of phase between components of the same frequency is obtainable readily. Power ranging from low to high values and over an extreme range of frequencies can be determined either by amplitude and power-factor measurements or directly from an elliptical figure, the area of which is proportional to the power. Fluctuating pressures can be recorded, direction can be indicated, and many other engineering problems too numerous to mention here can be expeditiously solved with the aid of the cathode ray tube.

In conclusion, it may be said that present-day cathode ray tubes are simple to use, are flexible in application, and can be used to advantage in the solution of many engineering problems.

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A complete bibliography on cathode ray tubes would be extensive. The following are a few references which will serve to guide the reader to other references.


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# Effect of Overloads on Transformer Life

**Effects of overloading on the life of oil-immersed self-cooled power transformers are discussed in this paper. Experience has shown that under average loads and ambient temperatures, a transformer rated for a temperature rise of 55 degrees C, has a very long life, and can be overloaded considerably for short periods with little loss in life.**

By
L. C. NICHOLS
FELLOW A.I.E.E.

Allis-Chalmers Mfg. Co., Milwaukee, Wis.

THERE is very little published information for telling the user of a transformer what the effect on the life of the transformer is, when it is operated at either high or low ambient temperatures, or when it is operated at high overloads for relatively long periods resulting in temperatures too high to operate continuously with safety. Any operation of the transformer consumes some of its life. Manufacturers of transformers are asked questions of the following nature:

1. What overload will a transformer carry without injury?
2. What overload will a transformer carry if the ambient temperature is 0 degree C, 10 degrees C, 20 degrees C, etc.?
3. What overload will a transformer carry for 1 or 2 hours following full load or following a load less than normal?
4. How long will a transformer carry an overload without injury if the temperature rise is greater than 55 degrees C?
5. What is the life of a transformer?
6. How often can these overloads be repeated?

Some of these questions already have been answered in A.I.E.E. publications.

Present A.I.E.E. rules allowing overloads at low ambient temperatures, and overloads allowed as given in the paper entitled "Overloading of Power Transformers," by V. M. Montsinger and W. M. Dann, published in the October issue of ELECTRICAL ENGINEERING, p. 1353–5, are very satisfactory from many standpoints, and yet they still leave something to be desired. What effect on the life of the transformer do these overloads have? If the transformer is operated within its rating, what is the life of the transformer? These questions cannot be answered definitely because it is practically impossible to gather exact data. However, on the basis of data presented in this paper, the following conclusions seem justified:

1. A transformer rated for a temperature rise of 55 degrees C has a very long life when operated under average loads and ambient temperatures.
2. A transformer can be overloaded considerably for short periods with very little loss in life.
3. Under the new proposed recommendations, emergency loads would consume less than $^1/_4$ of 1 per cent and recurrent overloads less than $^1/_{1000}$ of 1 per cent of the life of the transformer for each overload.
4. If a transformer is loaded at a constant load 24 hours a day in a 40-degree ambient temperature, then a transformer rated $^1/_3$ larger than the load should be used.

Full text of a paper recommended for publication by the A.I.E.E. committee on electrical machinery, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 30, 1933; released for publication Oct. 16, 1934. *Not published in pamphlet form.*

## Operation at Loads Greater Than Rated Load

Any insulating material deteriorates, and the deterioration is a function of both temperature and time. The higher the temperature the greater the rate of deterioration; experience indicates that the rate of deterioration doubles with every 8-degree C increase in temperature.

Most transformers are single rated, 55-degree C rise, and good for operation at an ambient temperature of 40 degrees C. This means that the hot spot temperature in the transformer is 105 degrees C. Present rules of the A.I.E.E. might indicate that a reasonably long life of 15 to 20 years could be obtained if the transformer were operated continuously at this temperature. This is not correct. Tests made by placing different kinds of insulating material in oil for a period of 5 years at a temperature of 90 degrees C show that the material at the end of that time has aged to such an extent that it is exceedingly brittle; a transformer with insulation in this condition would fail from mechanical injury of the insulation, if there was any movement of the insulation. Tests also have been made on insulation for very short periods of time and at much higher temperatures.

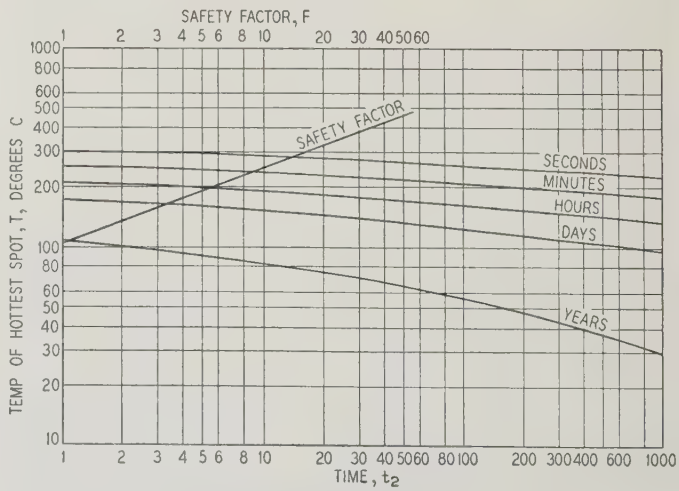



**Fig. 1. Life of transformer insulation versus hot spot temperature**

Per cent of life used, $L = 100(t_1/t_2)F$, where $t_1$ = time operated at hot spot temperature T, $t_2$ = life of insulation at temperature T, and F = safety factor

Experience of actual operation in the field with transformers steadily loaded at 100 per cent load at ambient temperatures approaching approximately 40 degrees C has shown that failures in these transformers have been due to deterioration of the insulation after comparatively short periods of time.

The curves of figure 1 show the life that can be expected from transformer insulation when operated continuously at any given hot spot temperature; data collected from various sources indicate that they are reasonably accurate and sufficiently conservative for practical use. These curves show that if a transformer were operated continuously at a hot spot temperature of 105 degrees C, the insulation would have a life of only $1^1/_3$ years. In order to be reasonably safe, if the temperature exceeds 105 degrees C, the expected life is divided by a factor varying from 1 at 105 degrees to 10 at 250 degrees. As an example of the use of figure 1, suppose a transformer is operated with a hot spot temperature of 150 degrees for 4 hours. The figure shows a life of 240 hours, but a factor of safety of 2.6 must be used. Therefore when operated for 4 hours at 150 degrees, one operation has consumed $100(^4/_{240})2.6$ or 4.3 per cent of the life. By means of this chart, if the time of operation at a given temperature is known, then the per cent life consumed can be calculated.

The first reaction of most people in looking at this chart will be that $1^1/_3$ years' life at a hot spot temperature of 105 degrees C is entirely too short, as this represents 100 per cent load continuously of a transformer rated for a 55-degree rise in a 40-degree ambient temperature, with an allowance of 10 degrees for hot spot. As an actual fact, a transformer is

**Table I—Loss in Life of an Oil-Immersed Self-Cooled Transformer† When It Is Overloaded Under Various Conditions**

| Load Conditions | Overload in Per Cent of Rated Load | Loss in Life in Per Cent of Total Life When Duration of Overload Is: 5 sec | 1 min | 5 min | 15 min | 30 min | 1 hr | 2 hr | 4 hr | 10 hr | 24 hr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 40° C ambient, 50% load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.002 | 0.005 | 0.016 | 0.054 | 0.217 | 1.870 | 6.000 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.006 | 0.023 | 0.075 | 0.420 | 2.000 | 20.800 | 85.000 |
| | 200 | 0.000 | 0.000 | 0.006 | 0.140 | 0.630 | 3.100 | 26.000 | * | * | * |
| | 250 | 0.000 | 0.000 | 0.076 | 5.000 | 30.000 | * | * | * | * | * |
| | 500 | 0.000 | 0.067 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 52.500 | * | * | * | * | * | * | * | * | * |
| 40° C ambient, full load followed by: | 125 | 0.000 | 0.000 | 0.003 | 0.016 | 0.034 | 0.075 | 0.230 | 0.580 | 2.290 | 6.000 |
| | 150 | 0.000 | 0.000 | 0.008 | 0.057 | 0.150 | 0.370 | 1.300 | 4.330 | 25.000 | 85.000 |
| | 200 | 0.000 | 0.000 | 0.069 | 0.890 | 3.000 | 12.000 | 78.000 | * | * | * |
| | 250 | 0.000 | 0.003 | 0.750 | 30.000 | * | * | * | * | * | * |
| | 500 | 0.000 | 0.880 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | * | * | * | * | * | * | * | * | * | * |
| 20° C ambient, 50% load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.009 | 0.030 | 0.188 | 0.600 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.009 | 0.042 | 0.200 | 2.500 | 10.500 |
| | 200 | 0.000 | 0.000 | 0.000 | 0.016 | 0.073 | 0.370 | 3.800 | 24.000 | * | * |
| | 250 | 0.000 | 0.000 | 0.009 | 0.680 | 4.000 | 27.500 | * | * | * | * |
| | 500 | 0.000 | 0.009 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 6.750 | * | * | * | * | * | * | * | * | * |
| 20° C ambient, full load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.009 | 0.025 | 0.063 | 0.229 | 0.600 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.006 | 0.014 | 0.040 | 0.150 | 0.500 | 2.710 | 10.500 |
| | 200 | 0.000 | 0.000 | 0.008 | 0.110 | 0.420 | 1.700 | 10.000 | 68.000 | * | * |
| | 250 | 0.000 | 0.000 | 0.104 | 4.600 | 22.000 | * | * | * | * | * |
| | 500 | 0.000 | 0.117 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 26.500 | * | * | * | * | * | * | * | * | * |
| 10° C ambient, 50% load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.012 | 0.075 | 0.220 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.016 | 0.068 | 0.750 | 3.500 |
| | 200 | 0.000 | 0.000 | 0.000 | 0.005 | 0.023 | 0.130 | 1.200 | 10.000 | * | * |
| | 250 | 0.000 | 0.000 | 0.003 | 0.200 | 1.600 | 10.000 | * | * | * | * |
| | 500 | 0.000 | 0.003 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 3.000 | * | * | * | * | * | * | * | * | * |
| 10° C ambient, full load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.011 | 0.007 | 0.087 | 0.220 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.002 | 0.005 | 0.014 | 0.050 | 0.158 | 0.920 | 3.500 |
| | 200 | 0.000 | 0.000 | 0.003 | 0.036 | 0.140 | 0.540 | 4.200 | 22.000 | * | * |
| | 250 | 0.000 | 0.000 | 0.037 | 1.500 | 8.500 | 44.000 | * | * | * | * |
| | 500 | 0.000 | 0.049 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 9.500 | * | * | * | * | * | * | * | * | * |
| 0° C ambient, 50% load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.005 | 0.031 | 0.096 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.006 | 0.028 | 0.250 | 1.100 |
| | 200 | 0.000 | 0.000 | 0.000 | 0.002 | 0.008 | 0.040 | 0.460 | 3.340 | * | * |
| | 250 | 0.000 | 0.000 | 0.001 | 0.078 | 0.540 | 4.000 | 78.000 | * | * | * |
| | 500 | 0.000 | 0.000 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 1.100 | * | * | * | * | * | * | * | * | * |
| 0° C ambient, full load followed by: | 125 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.010 | 0.037 | 0.096 |
| | 150 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.006 | 0.018 | 0.057 | 0.304 | 1.100 |
| | 200 | 0.000 | 0.000 | 0.000 | 0.012 | 0.046 | 0.210 | 1.300 | 9.180 | * | * |
| | 250 | 0.000 | 0.000 | 0.012 | 0.630 | 2.700 | 17.000 | * | * | * | * |
| | 500 | 0.000 | 0.015 | * | * | * | * | * | * | * | * |
| | 1,000 | 0.000 | * | * | * | * | * | * | * | * | * |
| | 2,000 | 3.850 | * | * | * | * | * | * | * | * | * |

* Over 100 per cent; transformer probably would fail.

† Data in this table are for a transformer rated as follows: copper temperature rise, 55 deg C; oil temperature rise, 40 deg C; ratio of losses, 2.75.

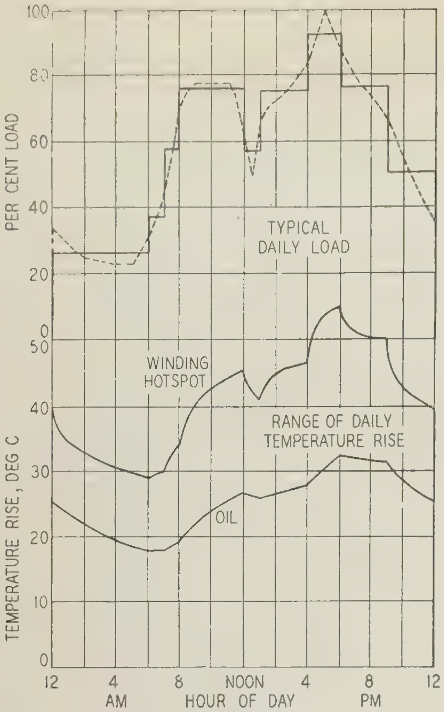



**Fig. 2. Typical daily load cycle of a transformer in service on a large electric power company system, and curves showing hot spot temperature of winding and oil**

practically never operated continuously at either a 40-degree ambient temperature or 100-per cent load.

A typical daily load on a transformer is indicated in figure 2 by a dotted line. This load cycle was obtained from a large electric power company, and represents the daily load cycle of that company's system. This is approximated by the heavy line for easy calculation. The hot-spot temperature rise of a typical transformer is shown in the lower part of this chart.

A transformer operated in the City of Pittsburgh, Pa., loaded as shown in figure 2 and with ambient temperatures equal to the monthly mean maximum temperature will have a life of 47 years as calculated from figure 1. If operated with ambient temperatures 8 degrees higher than that of Pittsburgh, the life would be 23 years.

## Overloads

Table I shows what loss in life in per cent may be expected when a transformer is overloaded under various ambient temperatures and when various overloads are applied for various times following full load and following 50-per cent load. As the temperature rise of the transformer is not much greater at 50-per cent load than at no load, these charts can be used for any load following no load. It is to be noted that with 125-per cent load and a 40-degree ambient temperature following 50-per cent load, practically none of the life is consumed until after a 15-min period, and in 24 hours 6 per cent of the life would be consumed. However, with 150 per cent load for 24 hours, 85 per cent of the life would be consumed. If, however, the ambient temperature is zero, only 1.1 per cent of the life would be consumed in 24 hours at 150-per cent load. In calculating this loss in life from resultant temperatures for various times, a transformer was selected that had 40-degree oil temperature rise and 55-degree copper temperature rise with a ratio of losses of 2.75. If the transformer had a greater ratio of losses than this, it could not be overloaded so much, but this data represents fairly accurately and conservatively what may be expected of practically any modern transformer. This table should be very valuable to operators, especially when emergency conditions necessitate overloading a transformer. For instance, a transformer operated in a 20-degree ambient temperature will carry 25 per cent overload for 24 hours and only 0.6 of 1 per cent of the life will be consumed, or it will carry much greater overloads for shorter periods with only a small percentage of the life consumed, as shown by the table.

## Calculation of Transformer Temperature Rise

Several charts have been prepared showing how the temperature rise of a transformer may be estimated when carrying various overloads for different times, provided certain information is available. What must be known are the iron loss and the copper loss at full load, temperature rise of the oil at full load, temperature rise of copper over the oil at full load, and weights of transformer core, copper, case, and oil. The temperature rise at practically any load can be determined from these figures. The ultimate temperature rise of the oil varies as the 0.8 power of the total loss. The ultimate temperature rise of the copper over the oil varies directly as the copper loss.

In figure 3 are shown heating and cooling curves for a typical transformer. Curves *A* represent what the

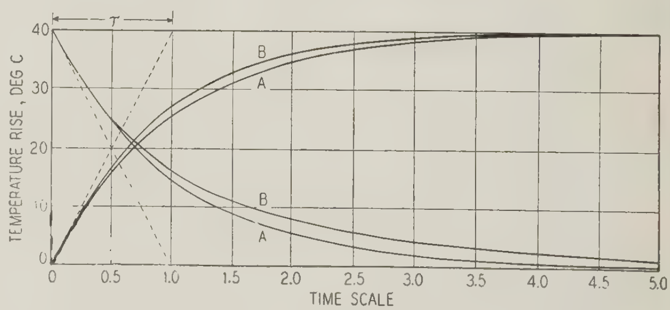



**Fig. 3. Heating and cooling curves for a typical transformer**

Curves A. Energy dissipation assumed to be directly proportional to temperature rise

Curves B. Energy dissipation assumed to be proportional to 1.25 power of temperature rise, but radiating surface reduced to give same final temperature as for curves A

heating and cooling would be if the temperature rise varied directly as the loss, which is how the temperature rise of copper over oil varies; curves *B* show what the heating and cooling would be if the temperature rise varied as the 0.8 power of the loss, which is how the oil temperature varies. In other words, the heat dissipation varies as the 1.25 power of the temperature. It may be noted by comparing curve *B* with curve *A* that while the initial rate of temperature rise and the final temperature rise is the

same for both, in curve $B$ the temperature rise is more rapid than in curve $A$. Also the cooling is at a less rapid rate, although they both start at the same initial rate.

If these heating and cooling curves were converted into straight lines, they could be drawn more easily, especially when it is desired to draw heating curves for many different loads.

If a transformer heats up according to a known law, say with heat dissipation varying as the 1.25 power of the temperature rise as in curve $B$, it starts at an initial rate that can be determined from the losses, weights, and specific heat of the material in the transformer, and finally reaches an ultimate temperature after continuous operation at a given load. There is only one curve that can be drawn following this law with the same initial rate and the same ultimate temperature rise.

Figure 4 shows how the time scale can be changed to convert the curve into a straight line. Where this straight line crosses the ultimate temperature the time must be infinity, and where the temperature rise is zero, the time also must be zero. Any convenient length may be chosen for this time scale that will be marked zero to infinity. The unit of time chosen is that time required for the temperature to reach the ultimate value, if the rise continued at the initial rate. In this length of time the temperature rise, following the 1.25-power law, reaches 68 per cent of the ultimate value; therefore, unit time on the time scale will be at a point 68 per cent of its total length from the zero point. Other points on the time scale are easily laid off as indicated.

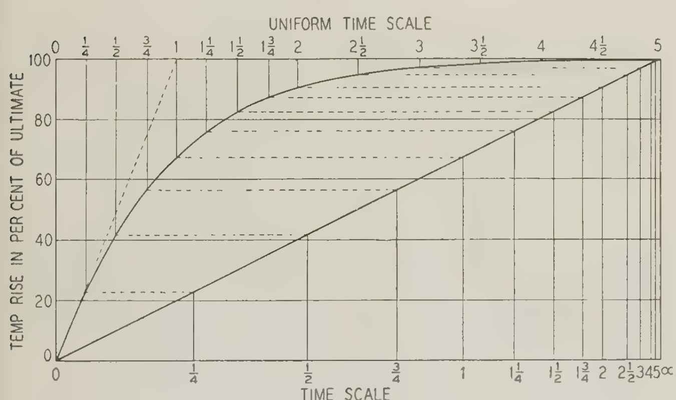



**Fig. 4. Graphical method of laying off scale to convert transformer heating curve to a straight line**

Time unit = time to reach ultimate temperature rise at initial rate

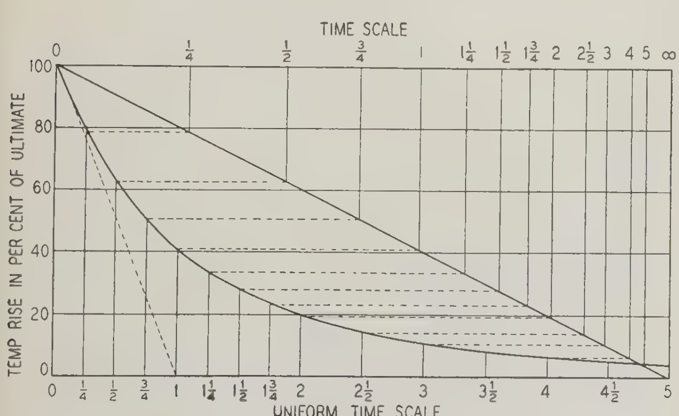



**Fig. 5. Graphical method of laying off scale to convert transformer cooling curve to a straight line**

Time unit = time to reach ultimate temperature drop at initial rate

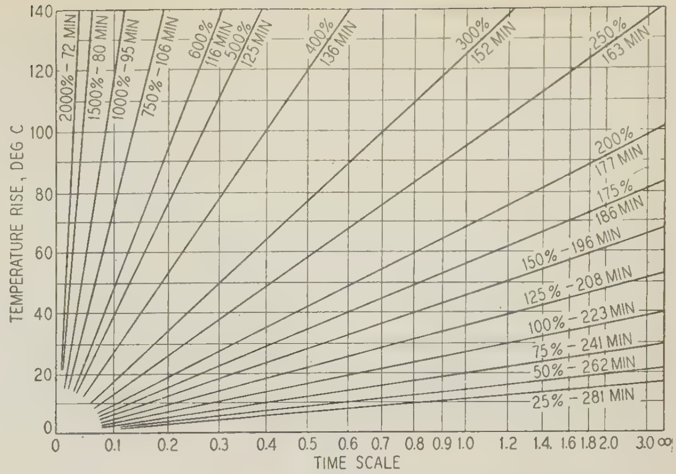



**Fig. 6. Straight-line transformer heating curves drawn as shown in Fig. 4**

Energy dissipation proportional to 1.25 power of temperature rise

Time unit = ultimate temperature rise ÷ initial rate of rise

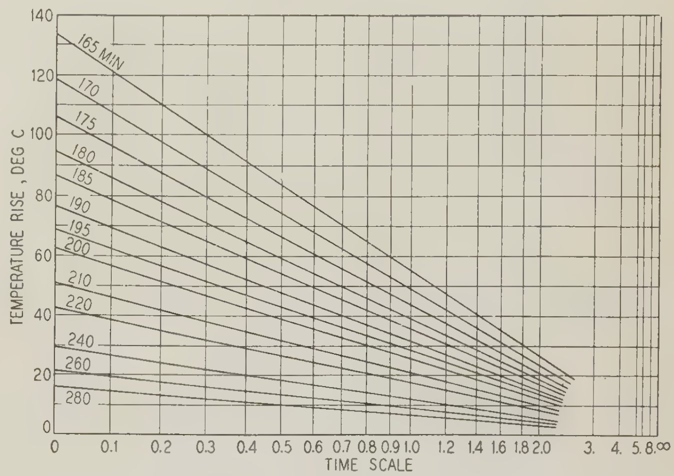



**Fig. 7. Straight-line transformer cooling curves drawn as shown in Fig. 5**

Energy dissipation proportional to 1.25 power of temperature rise

Time unit = initial temperature rise ÷ initial rate of fall

Similarly, figure 5 shows how a cooling curve can be made into a straight line.

A family of heating curves drawn as just outlined is shown in figure 6. These curves represent temperature rise of the oil under various loads and for various times for the particular transformer mentioned previously, but are fairly typical and may be used with fair accuracy for any transformer. At 100 per cent load the ultimate temperature rise is 40 degrees C. A straight line then can be drawn between zero and 40. If the temperature rise of the oil varies as the

0.8 power of the total loss, then the ultimate temperature rises for other loads can be calculated. For this purpose the resistance of the copper is taken as remaining constant and is the resistance at 75 degrees C. Straight lines then can be drawn very readily for other loads. These are marked in figure 6 in per cent as 125 per cent, 150 per cent, 175 per cent, etc.

The unit of time, however, remains to be calculated. As defined previously, this unit of time is the time required for the oil to reach ultimate temperature if no heat was dissipated. To calculate this, the loss in the transformer, the weights of materials in the transformer, and the specific heat of the materials must be known.

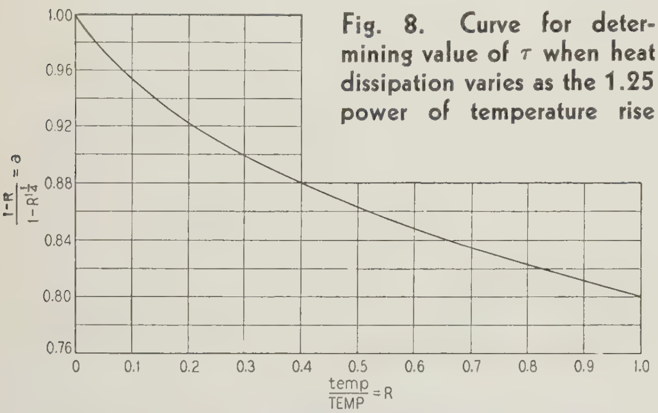



**Fig. 8. Curve for determining value of $\tau$ when heat dissipation varies as the 1.25 power of temperature rise**

$\tau$ = time required to reach ultimate temperature at initial rate of temperature change

Temp. = ultimate temperature rise on heating or initial temperature rise on cooling

temp. = initial temperature rise on heating or ultimate temperature rise on cooling

K = heat capacity of body (watt-minutes per degree C)

k = watts loss ÷ (ultimate temperature rise)$^{1.25}$

$$\tau = \frac{K}{k}\left(\frac{\text{Temp.} - \text{temp.}}{\text{Temp.}^{1.25} - \text{temp.}^{1.25}}\right) = \frac{aK}{k\ \text{Temp.}^{0.25}}$$

$$\text{If temp.} = 0,\ \tau = \frac{K}{k\ \text{Temp.}^{0.25}}$$

As all the material in the transformer does not come up to the same temperature as the hottest oil, only $^2/_3$ of the weight of the case and $^3/_4$ of the weight of the oil are used in these calculations. This unit of time, $\tau$, is equal to $A(C + D + E) + G$, where $A$ is the ultimate temperature rise of the oil, $C$ equals 3.64 times pounds of core plus $^2/_3$ of the pounds of the case, $D$ equals 2.93 times pounds of copper, $E$ equals 14.23 times $^3/_4$ of the pounds of oil, and $G$ is the total loss.

As the ultimate rise $A$ does not vary directly as the loss but as the 0.8 power of the loss, the unit of time is different actual time for each load. This unit of time has been calculated for the various loads and indicated on the curves of figure 6 immediately adjacent to the per cent load. With these straight lines drawn, the temperature rise of the oil for any load for any time can be read. For instance, suppose a transformer starts cold and 100-per cent load is applied for 8 hours, or 480 minutes. As the unit of time is 223 minutes, 8 hours is represented by 2.15 on the time scale, and the temperature rise of the oil is 36.5 degrees C. Suppose 50-per cent overload is applied for 2 hours. The 150-per cent curve at 36.5 degrees C is 0.7 on the time scale. Two hours from that time is 120 minutes, and as $\tau$ for this curve is 196 minutes, add 0.61 in time, making a total of 1.31; this gives an oil temperature of 52.5 degrees C. Similarly, the temperatures for any successive loads that would cause an increase in temperature can be calculated.

The cooling that can be expected from any temperature with the transformer disconnected from the line is shown by the curves of figure 7. The value of $\tau$ to be used depends upon the initial temperature and is the same value as would be used on the heating curve (figure 6) according to the ultimate temperature rise. At 40 degrees C, $\tau$ would be 223 minutes, the same as shown in figure 6 for 100-per cent load which gave an ultimate temperature rise of 40 degrees. With a transformer having an initial oil temperature of 51 degrees C, $\tau$ is 210 minutes, or in 210 minutes the oil would cool off to 20 degrees C.

If a transformer, however, is operated at a load that would cause the oil to cool off from its initial temperature, then figure 7 must be used, but a straight line must be drawn from the initial temperature rise on the left side of the chart to the ultimate temperature rise on the right side of the chart, this ultimate temperature rise of course being determined from the energy generated in the transformer. However, the value of $\tau$ under this condition must be calculated according to figure 8. With the ratio $R$ of the ultimate temperature to the initial temperature determined, it is possible to read multiplier $A$ by which $\tau$ as determined in figure 7 for the initial temperature must be multiplied to give the new value of $\tau$ to be used.

The curves in figure 9 are for use in calculating the temperature rise of the copper over oil. As the temperature rise of the copper over oil varies directly as the copper loss, these curves can be used both for

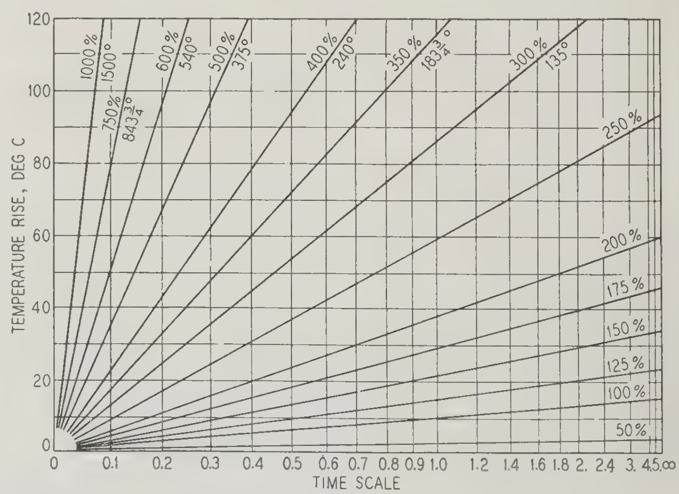



**Fig. 9. Curves for calculating temperature rise of the copper over that of the oil in a typical power transformer**

Copper loss of transformer at 100 per cent rated load = 27 kw; weight of copper = 2,610 lb; time unit = 4.25 min; unit time (in minutes) = 2.93 × temperature differential ÷ watts loss per pound

Temperature differential varies as square of load

heating and cooling. The unit of time in minutes is equal to 2.93 times the pounds of copper times the ultimate temperature rise of the copper over the oil divided by the copper loss, or is equal to 2.93 times the temperature rise of the copper over oil divided by the watts loss per pound. In this particular example these curves are drawn with 15-degree differential between copper and oil for 100-per cent load, this temperature rise of copper and oil varying as the square of the load for other loads. For this particular transformer the unit of time is 4.25 minutes; by referring to the curve it may be seen that in 4.25 minutes the temperature of the copper would be 10 degrees C higher than that of the oil at 100-per cent load. These curves show that if the load is applied for 20 minutes the copper will reach its ultimate temperature rise over the oil, and therefore these curves need not be used unless the overloads are for less than 20 minutes. If now 200-per cent load is applied for $4^1/_4$ minutes following full load, the 200-per cent load curve should be used; 15-degree C rise is at 0.29 on the time scale, and $4^1/_4$ minutes more would be 1.29 and the oil rise 43 degrees C. Similarly temperatures during cooling can be found by using this same chart, the value of the time scale remaining the same. It is only necessary to draw a straight line from the initial temperature on the left-hand scale to the ultimate temperature for the load in question on the right-hand scale and read directly the temperature for any intermediate time as indicated by the time scale.

# A Thermionic-Tube Measuring Instrument

**A universal measuring instrument for communication circuits has been developed which has a number of advantages over previous methods of obtaining measurements in such circuits. This thermionic-tube instrument gives direct measurements of current, voltage, power factor, or power in communication circuits and is accurate over a wide range of frequencies.**

By
TOM B. WAGNER Portland, Ore.

THE A-C power taken by communication apparatus is seldom measured directly. This is due primarily to the lack of a satisfactory direct reading power instrument such as the wattmeters used in commercial power circuits. The power taken in communication circuits is usually only a fraction of a watt and sensitive instruments are accordingly required. Then, too, communication frequencies cover the wide band from about 50 cycles to millions of cycles per second. This prevents the use of ordinary commercial power instruments.

Power measurements in communication circuits are determined from $I^2R$ values; the current is read with a thermocouple instrument and the effective resistance is measured with a bridge. The resistance $R$ is, however, sometimes difficult to measure; for example, the resistance offered by a loud speaker varies with the current used. Also, this method is slow and laborious, and while it can be employed, it does not offer the same flexibility that can be obtained with direct reading devices such as ordinary wattmeters.

With the appearance of the Wunderlich thermionic tube, having 2 symmetrical and hence equally-effective control grids, the possibility was recognized of utilizing this tube as a basis for a vacuum tube wattmeter. By impressing a voltage proportional to the current taken by the load being measured on one grid and the voltage across the load on the other grid, it seemed possible that the alternating current in the plate circuit of the tube would be proportional to the product of the load voltage $E$, the load current $I$, and the cosine of the angle between $E$ and $I$. As a result of this investigation it was found that the device not only operated as a wattmeter, but it could readily be used to give voltage, current, or power factor separately, thus supplying a means of measuring the 4 fundamental electrical quantities.

Full text of a paper presented at a joint meeting of the Institute's Portland Section and Oregon State College Branch, May 20, 1933, and subsequently awarded the Institute's 1933 Branch paper prize. Manuscript submitted May 31, 1933; released for publication July 2, 1934. *Not published in pamphlet form.*

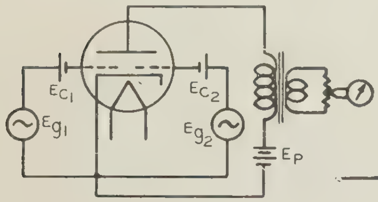
## Theoretical Considerations

The Wunderlich tube has an indirectly heated cathode and is not unlike the common type 27 tube except for 2 control grids instead of the conventional single control grid. In Fig. 1 the arrangement of the electrodes in the Wunderlich tube is shown.

In the instrument here described, the tube was biased to operate essentially as a linear amplifier. That is, when an a-c voltage $E_g$ is superimposed on the d-c bias $E_c$ of one of the control grids of the tube, this a-c voltage affects the electron flow to the plate of the tube in the same relation as the polarity and magnitude of the a-c impressed on the grid. This process is shown graphically in Fig. 2. This pulsating plate current is passed through a transformer to separate the d-c from the a-c component. The

alternating voltage appears on the secondary side of the transformer and operates a suitable indicator.

If an a-c voltage of the same frequency is simultaneously impressed on the other control grid of the tube the electron flow to the plate will depend upon the magnitudes and phase relations of these 2 a-c



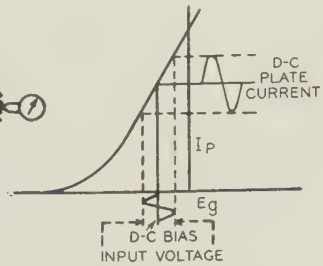




**Fig. 1 (left). Fundamental circuit of the universal measuring instrument for communication circuits**

**Fig. 2 (right). Grid characteristics of the Wunderlich tube**

voltages. That is, if in-phase a-c voltages of 3 volts are placed on each grid of the tube, the indicator will give a certain reading. After changing the grid voltages to 2 volts on one grid and 4 volts on the other grid the total grid input voltage is still 6 volts, and the indicator reads the same as before. It was found by tests that this was about the greatest difference in the a-c grid voltages that could be employed to give the same indicator reading as for equal a-c grid voltages (the sum of the a-c voltages being the same in either case).

## Description of the Instrument

One of the most important features of this instrument (shown in Fig. 3) is the possibility of inserting it in a circuit without disturbing the circuit. In Fig. 4 a complete diagram of the instrument is shown and the photograph shows the parts and their arrangement as used in the experimental study. The resistance of the potentiometer $R_1$ was 4 ohms. It was found necessary to use a low value of resistance for this series resistor in order to keep the power losses and $IR$ voltage drop in the instrument as low as possible.

A 3-stage resistance-coupled vacuum-tube amplifier was used to increase the voltage drop across $R_1$ sufficiently to excite one of the grids of the Wunderlich tube. This is the current measuring part of the circuit. It might appear that the amplifier would cause a phase distortion or change in wave shape, but this is not true. Observation with an oscillograph showed no phase or wave form distortion between the input and output circuits of the amplifier.

The resistor $R_2$ is connected in parallel with the output circuit and is of high resistance to keep the power losses low. This is the voltage measuring part of the instrument.

If the a-c voltages across $R_1$ and $R_2$ are substituted for the a-c generators in the grid circuits of the tube in Fig. 1 the device is complete, and the thermocouple current will depend upon the magnitudes and

**Fig. 3. Equipment of the universal measuring instrument for communication circuits**

phase relations of these voltages. To have satisfactory coupling between the plate circuit of the tube and the low resistance thermocouple used in the indicator circuit a high ratio step-down transformer giving suitable transfer impedance was used.

## Operation as an Ammeter

For use as an ammeter $R_2$ is set at zero and $R_1$ and $R_3$ are set at predetermined points, depending upon the magnitude of current to be measured. The microammeter connected to the thermocouple is the indicator, and from an over-all calibration curve (Fig. 5) the current through $R_1$ is read.

## Operation as a Voltmeter

For use as a voltmeter $R_1$ and $R_3$ are set at zero and $R_2$ is set at some predetermined point, depending upon the magnitude of voltage to be measured. The voltage is read from an over-all calibration curve (Fig. 6) plotted against readings of the microammeter.

## Operation as a Wattmeter

For power measurements $R_1$ and $R_2$ are set at given points, depending upon the current and voltage magnitudes. The microammeter then gives

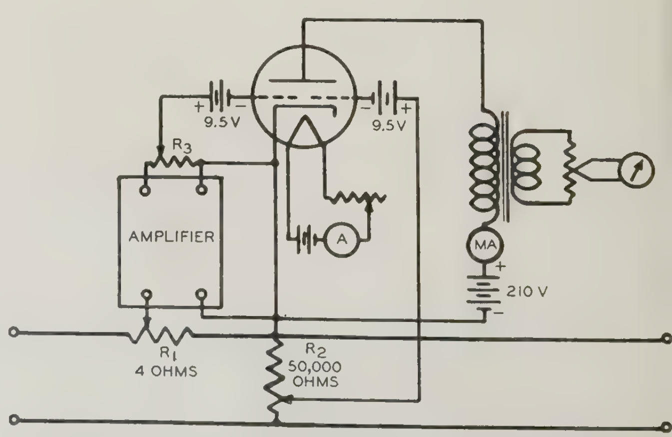



**Fig. 4. Complete circuit of the universal instrument used in securing calibration curves**

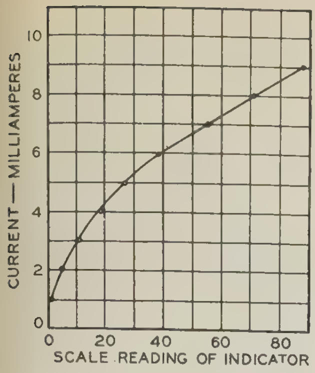



**Fig. 5. Current calibration for universal instrument**

$E_d = -9.5$ volts $E_p = 210$ volts

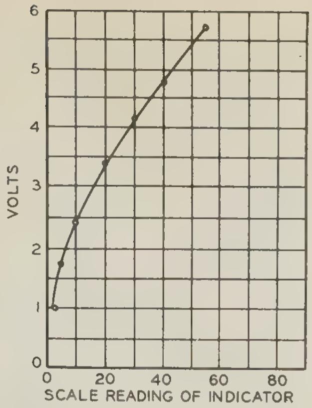



**Fig. 6. Voltage calibration for universal instrument**

$E_d = -9.5$ volts $E_p = 210$ volts

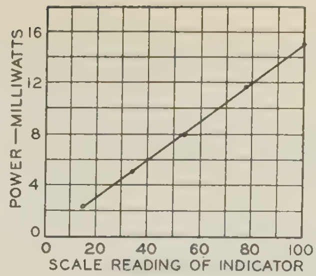



**Fig. 7. Power calibration for universal instrument**

$E_d = -9.5$ volts $E_p = 210$ volts

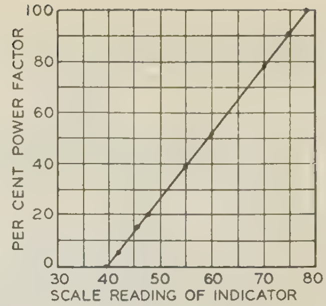



**Fig. 8. Power factor calibration for universal instrument**

Each grid set to cause indicator to read 20

$E_d = -9.5$ volts $E_p = 210$ volts

an indication of the power being consumed by the load. As for the ammeter and voltmeter, the power values are read from an over-all calibration curve (Fig. 7). In using the instrument care should be exercised that the maximum a-c voltage does not exceed the d-c bias voltage on the control grids of the tube.

## Operation as a Power Factor Meter

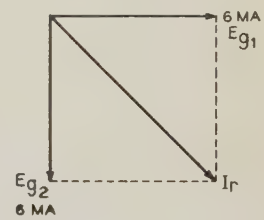
For operation as a power factor instrument $R_1$ and $R_2$ are first set at zero. Resistor $R_2$ is then varied until the microammeter connected to the thermocouple reads an arbitrary scale (in these tests) of 20, corresponding to 6 ma of thermocouple current. The dial reading of $R_2$ is recorded. Then $R_2$ is brought back to zero. The resistor $R_1$ is then set at some convenient point, and $R_3$ is varied until the microammeter again reads 20.

With $R_1$ and $R_3$ left at these points, $R_2$ is set on the dial reading previously obtained. The magnitude of the voltages on each grid is now the same, although these voltages do not necessarily have the same phase relations. If they have the same phase relations the microammeter will read 78 (12 ma thermocouple current) as shown on the calibration curve (Fig. 8) for 100 per cent power factor. If there is a phase difference between these 2 voltages the microammeter will read less than 78 as shown by the curve (Fig. 8), giving an indication of the power factor of the load.

The calibration was obtained at various power factors with a load composed of pure capacitance and resistance in series. Knowing the $IR$ drop from the product of the load current and resistance, and dividing this $IR$ drop by the total load voltage measured with a voltmeter, the per cent power factor was obtained. While the curve is plotted from experimental data, it is possible to check each end of the curve by simple calculations.

When the load has unity power factor the current reading of the microammeter should be double that produced when setting either grid from equal a-c potentials. Under typical operating conditions a scale reading of 20 indicates 6 ma of thermocouple current. Doubling this value of 6 ma gives 12 ma, and the scale reading on the microammeter for 12 ma is 78, which is the correct reading for 100 per cent power factor. For zero power factor the a-c grid voltages are 90 deg out of phase and can be represented by current vectors as in Fig. 9. The current $I_r$ is the vector sum of the 2 equal currents, or $1.414 \times 6$ ma $= 8.5$ ma. This 8.5 ma corresponds to a scale reading on the microammeter of 39.5. Therefore, a scale reading of 78 will give unity power factor, and 39.5 gives zero power factor. This checks very well with the experimental calibration curve of Fig. 8. In a similar manner, using either trigonometric or graphic solution, other points on this curve can be checked.

**Fig. 9. Vector diagram of grid voltages at zero power factor**




## Conclusions

1. The error of the instrument as used in this investigation is approximately 2 per cent for frequencies ranging from 100 cycles to 3,000 cycles.

2. The instrument would undoubtedly work very well at much higher frequencies if proper shielding and other construction refinements were employed.

3. The instrument consumes negligible power from the source, and does not affect circuit conditions materially.

4. The calibration curve for power factor can be checked mathematically.

5. Four measuring instruments can be included in one, namely, a voltmeter, an ammeter, a wattmeter, and a power factor instrument.

6. The chief objection to the instrument is the indirect method of measuring power factor, requiring several adjustments to make a reading, thus increasing the chances for errors.

7. Although exhaustive tests were not made to determine the error due to poor wave form, it does not appear that the error would be greater than with other measuring instruments. Moreover, in most laboratory tests for which this instrument is particularly adapted, sine waves are used.

# Measurement of Noise From Small Motors

An analysis and summary of some of the concrete problems and considerations involved in the measurement of noise caused by fractional horse power motors are presented in this paper. Some experimental data and several important conclusions are given, but much remains to be done before standardization is possible. Desirable characteristics of a noise meter for this application are pointed out.

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MEASUREMENT of the total noise of a small motor undoubtedly presents a different aspect from the standpoint of a practical motor engineer than it does from an abstract physical viewpoint. If motor noise is to be measured as a routine test in quantity production, it is necessary to develop instruments and a technique whereby some indication of this noise can be made near the production line in a noisy factory. It is necessary, therefore, to develop means for measuring or obtaining an indication of the motor noise in noisy surroundings, where the noise is likely to vary considerably and where there are likely to be all sorts of intermittent noises, such as hammering, that would affect a noise meter considerably. The quietness of the modern fractional horse power motor renders this problem the more difficult. At this immature stage of the art, it is unwise to attempt to recommend any instrument or technique for purposes of standardization. It is hoped, however, that this presentation of some of the aspects of the problem will prove of value to future investigators and will stimulate other papers on this subject.

The principal points brought out in this paper and the conclusions reached may be summarized as follows:

1. Motor noise should be classified into 2 groups: (a) air-borne noise, and (b) transmittable noise, or potential noise that may be transmitted through the mounting structure.

2. A "sound proof" box for measuring air-borne noise should have sound insulation that reduces the noise level at least 40 decibels. (This is based upon a factory noise level of 70 to 80 decibels.)

3. The interior of this box should be acoustically dead, that is, it should have as short a time of reverberation as possible. Also, no 2 interior walls should be parallel, in order to minimize errors from standing waves.

4. The box should be large enough so that a reasonable spacing, say a foot, between the microphone and the motor can be used.

5. For measuring air-borne noise, the motor should be mounted on an effective noise insulating base.

6. While it is desirable to have the microphone a foot away from the motor, the microphone should be of such a type and construction that it can be placed nearer the motor when necessary.

7. A satisfactory type of microphone remains to be developed. It does not appear that the condenser microphone, the crystal microphone, or the moving coil microphone as at present developed are entirely satisfactory.

8. It is important that the meter should be able to read both an unweighted and a weighted total noise.

9. In a practical noise meter, provision should be made so that the signal indicated on the output meter can be listened to by means of high quality headphones. A pair of headphones, and a little judgment as to the quality of the sound, are often of great assistance in determining whether or not a reading is of any value. When using the headphones, the signals should be unweighted.

10. The question of pitch, in connection with motor noise, often is raised. A quantitative measurable indication as to whether the noise is composed mainly of low or high frequency components is highly desirable. For this purpose, the author proposes the term "quality index," abbreviated QI, which is defined as the difference between the weighted and unweighted intensities, expressed in decibels.

## Measuring Motor Noise in a Large Room

Before plunging deeper into the subject, it may be well to mention the type of noise meter used for the greater part of the experiments discussed in this paper. The meter used was described fully by Osbon and Oplinger (see "A New Portable Meter for Noise Measurement and Analysis," *Journal* of Acoustical Society of America, July 1933, pages 39–45). The sound pick-up is a standard high quality condenser microphone of the type extensively used in broadcasting and sound recording. It has a 3-stage amplifier included in the microphone housing. The electrical output from this microphone is fed into a high-quality 3-stage transformer-coupled amplifier with a calibrated attenuator in the input circuit and a calibrated meter to measure the output. The system is arranged to give a flat frequency response from 100 to 6,000 cycles per second. A weighting network that gives an over-all response approximating the 50 decibel loudness contour of the standards proposed by the American Standards Association can be switched into the circuit at will. (See "Proposed Standards for Noise Measurements," by Harvey Fletcher,

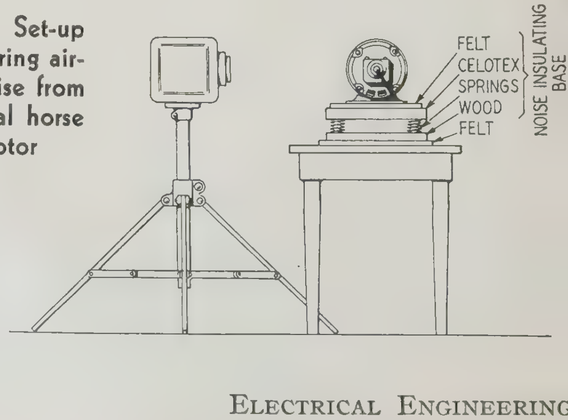


**Fig. 1. Set-up for measuring air-borne noise from a fractional horse power motor**

Full text of a paper recommended for publication by the A.I.E.E. committee on electrical machinery, and scheduled for presentation at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 1, 1934; released for publication Oct. 17, 1934. *Not published in pamphlet form.*

Electrical Engineering, volume 52, November 1933, pages 744–6.) A jack is provided so that it is possible to listen, by means of headphones, to the signal being picked up by the microphone for measurement.

To form an idea of the sound field surrounding a small motor, a typical motor was chosen and mounted on a noise insulating base, as shown in figure 1. The base and motor were placed on a small table in the center of a noise proof room which was approximately 12 feet square. Figure 2 shows the measured weighted intensity levels at various distances from the motor in various directions. Figure 3 represents a similar test on another typical motor.

Note: *All decibel figures given in this paper are based upon a reference level of $10^{-16}$ watts per square centimeter.*

The general tendency seems to be for the motor noise to become the more independent of direction of motor, the farther the microphone is placed from the motor. At 2 inches from the motor the sound in different directions may vary by 10 decibels or more, but at a distance of 1 foot this variation is reduced to 2 or 3 decibels.

How far the microphone should be placed from the motor merits consideration. It should be far enough from the motor to obtain an over-all indication of the average noise emitted by the motor. It should be placed near enough, however, so that reflected waves at the microphone will be negligible in intensity compared with the direct sound from the motor, and also near enough that the intensity of the signal in the microphone due to the motor noise will be substantially greater than that of the general noise of the room, say 10 decibels greater, as recommended by P. L. Alger. (See "Progress in Noise Measurements," Electrical Engineering, volume 52, November 1933, pages 741–4.) Care should be taken that air currents from the ventilating fan do not impinge directly upon the microphone diaphragm. Care also should be taken to avoid errors due to localization of sound in the motor, such as in ball bearings or in noisy brushes. The motors on which data were given in figures 2 and 3, did not have strongly localized sources of sound.

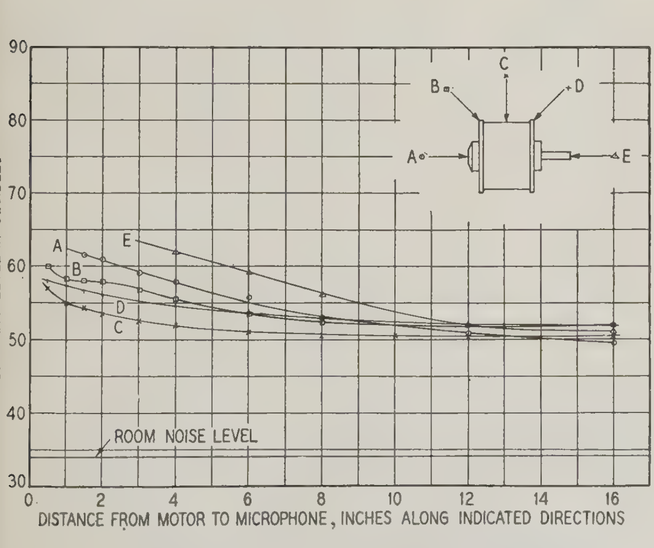


**Fig. 2. Exploration of the sound field surrounding a typical small motor in free air**

Most of the subsequent measurements on motors discussed in this paper were taken in the $C$ direction, that is, with the motor shaft perpendicular to an imaginary line drawn from the microphone to the motor. Where possible this distance was 1 foot, but it was often necessary to shorten this distance to $2^1/_4$ inches.

The preceding paragraphs were concerned with the measurement of the inherent or air-borne noise. In many motor installations, the transmitted noise, that is, the noise radiated by the base upon which the motor is mounted, is of more importance than the air-borne noise. The noise of 3 motors was measured, with the microphone 1 foot from the motors, first on a noise insulating base, as shown in figure 1, and second on a small pine table the top of which was approximately 18 inches square. The following results were obtained:

| | On Noise Insulating Base | On Pine Table |
|---|---|---|
| Motor 1 | 48 decibels | 50 decibels |
| Motor 2 | 54 decibels | 61 decibels |
| Motor 5 | 55 decibels | 68 decibels |

These results show strikingly the effect of the motor mounting. Motor 1 was provided with steel mounting springs which transmitted but little of the inherent torsional vibration of the motor to the base; motors 2 and 5 were mounted rigidly.

Any appraisal of small-motor noise must take into account transmittable as well as air-borne noise. One method proposed for measuring the transmittable noise is to mount the motor on top of a box and measure the noise intensity inside the box, with the motor running. This method is fraught with certain difficulties, however. An alternative method tried by the author for comparing relative transmittable noises of motors was to place a wooden board on top of the noise insulating base shown in figure 1, and allow the motor to run on this board. This method was partially successful, but not entirely satisfactory, because any slight warping of the board would cause the motor to rattle and render the readings useless.

## Noise Measurement in a Small Chamber

*Theory.* The preceding considerations apply to the measurement of motor noise in a very quiet room. In a noisy factory, it is expensive and difficult, if not impractical, to construct a "noise proof" room sufficiently quiet so that the noise of quiet fractional horse power motors can be measured with a noise meter. The most logical idea, then, would be to place motor and microphone in a small "sound proof" box. One way of constructing such a box would be with the following ends in view:

1. To have sound-insulating walls to keep out room noise.

2. To intensify the motor noise to raise it above the noise level inside the box; this can be done by making the box (1) small in volume, and (2) with hard reflecting interior walls, or (3) what amounts to the same thing, with the longest possible time of reverberation.

Problems involved are:

1. Intensification without distortion.

2. Minimization of errors from standing waves. Probably the most practical way of doing this is by constructing the box so that no 2 sides are parallel.

An alternative to the construction with no 2 sides parallel would be to construct the box with an interior of sound-absorbing walls, making the box as nearly accoustically dead as possible. Because of its apparent advantages, it was decided to conduct an experimental investigation on the first mentioned type of box.

*Experimental Data.* As a measure of the quality of a sound, the author suggests the term "quality index," abbreviated QI, and this is defined as the difference, in decibels, between the unweighted and weighted measurements of intensity. For a 1,000 cycle pure tone, the quality index is zero. For a pure tone of 120 cycles, using the 50 decibel contour, the quality index is approximately 15. In general, a large quality index indicates a relatively large proportion of low frequency components in the noise.

A box with no 2 sides parallel and with outside dimensions as given in figure 4 was constructed of mahogany $^5/_8$ inch thick, and the interior walls were left hard and smooth. Tests were made to determine the amount of sound insulation that could be obtained. For these tests, the box was suspended in a noise proof room from a spring fastened to the ceiling; the spring was deflected about a foot by the weight of the box and microphone inside. The following results were obtained:

| | Cover Off | | Cover On | | |
|---|---|---|---|---|---|
| | Noise Level, Decibels | QI | Noise Level, Decibels | QI | Reduction in Noise Level Due to Box |
| No machines running | 42 | 11 | 41 | 6 | 1 |
| Vacuum cleaner | 69 | 1 | 52 | 6 | 17 |
| Electric drill | 82 | 0 | 63 | 0 | 19 |

It is disturbing, but very important, to note at low levels an almost negligible apparent reduction of surrounding noise. This is probably because of the residual microphone and tube noises of the meter.

It is observed also, that high frequency noises are reduced more effectively by the box than are low frequency noises. Further experiments made to check this point demonstrated that the walls of the box would reduce a 60 cycle tone by 7 decibels, a 250 cycle tone by 11.5 decibels, and a 1,000 cycle tone by 23.6 decibels.

Attempting to obtain a further reduction in noise level inside this wooden box, the latter was placed inside a refrigerator cabinet and the space between the outside of the box and the inside of the refrigerator filled with jute. A refrigerator cabinet, with hard steel walls, separated by jute or good sound absorbing material, makes excellent sound insulation except that the steel is so thin that it easily can vibrate like a diaphragm. The whole assembly of refrigerator, wooden box, and microphone was mounted on springs so as to be isolated from floor vibrations. Tests were made to determine the reduction in noise level obtainable from the sound insulation. At high external noise levels the following results were obtained:

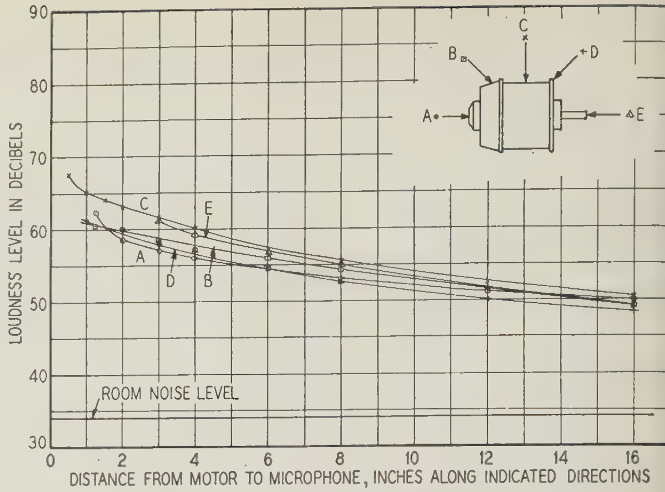


**Fig. 3. Exploration of the sound field surrounding a typical small motor in free air**

1. Average reduction from wooden box only, 22.5 decibels.

2. Average reduction from refrigerator only, 21.7 decibels.

3. Average measured reduction from both, 42.3 decibels.

In spite of the fact that this combination should reduce the interior noise 40 decibels below the external noise, it was found impossible to get a reading below 34 decibels inside the box, even with an external noise intensity of only 40 decibels. Again, this is probably because of the residual noise of the microphone and tubes.

Three motors were selected for noise measurements under 3 separate conditions: (1) in free air, (2) in wooden box with one side open, and (3) with box closed inside the closed refrigerator cabinet. In all tests the motor was mounted on the noise insulating base shown in figure 1. The results are as follows:

| | Motor 1 | | Motor 2 | | Motor 3 | |
|---|---|---|---|---|---|---|
| | Noise Level, Decibels | QI | Noise Level, Decibels | QI | Noise Level, Decibels | QI |
| Free air, $2^1/_4$ in. from microphone | 55.8 | 3.3 | 60 | | 7.5 | 61.3 | 2.0 |
| In non-parallel-sided box, box open | 58.7 | 7.0 | 64.5 | 11.4 | 65.6 | 10.9 |
| In non-parallel-sided box, box closed | 61.7 | 4.7 | 62.6 | 5.8 | 65.5 | 4.1 |
| Intensification due to box | 5.9 | | 2.6 | | 4.2 | |

The following conclusions can be deduced from these results:

1. Intensification of signal is too small, only about 4 decibels, to

be of practical assistance. It is doubtful if any more intensification than this can be obtained.

2. Intensification is accompanied by an erratic and unpredictable distortion of the quality.

3. It is interesting to note that, for 2 of the 3 motors, the measured noise was louder with one side of the box open than it was with the box totally closed.

4. It is also interesting to note that with the box open, the low frequencies were much more prominent than they were with the box closed or with the motors in free air.

Since intensification was the primary reason for constructing the box, small in size, and with hard sound-reflecting interior walls, the author, as a result of these experiments, is led to the conclusion that a noise testing box for small motors should have an acoustically dead interior and as short a time of reverberation as possible. Inasmuch as perfect sound-absorbing interior walls are impossible to obtain, errors due to standing waves should be minimized by constructing the interior so that no 2 sides are parallel.

## Noise Meters

*The Microphone.* The condenser microphone is recognized generally as a high quality microphone, with the desirable characteristic of a flat frequency-response curve. It is used extensively in radio broadcast work, and in high-fidelity sound recording. It has been used extensively and successfully as the sound pick-up for noise meters. Under ideal conditions it can be used successfully for measuring noise from fractional horse power motors. All the data in figures 2 and 3 were taken with a condenser microphone, and it may be noted that the room noise level was too low to cause any measurable error in the readings. However, while under ideal conditions, the residual noise level is low enough, this level seems to be disproportionately raised in the presence of large low frequency components of noise at, or near, the threshold of hearing. In a manufacturing plant, such noises apparently will penetrate the best sound insulation that can be devised and will affect the microphone. The noise thus picked up in a "sound proof" room surrounded by machinery sounds not like machinery noise, but like "air rush" against the microphone diaphragm. A motor running in this room at some distance from the

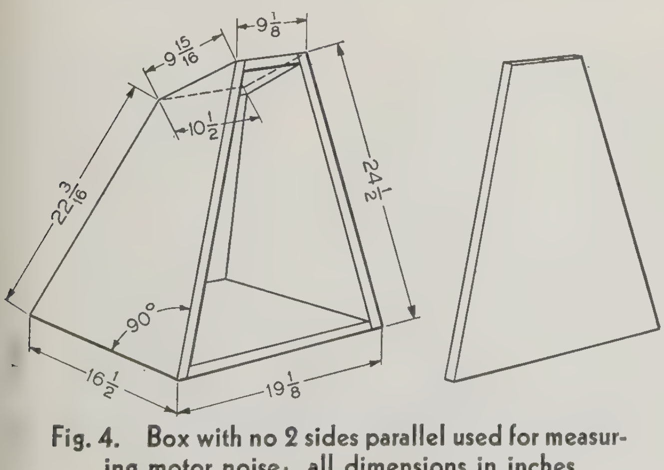


**Fig. 4. Box with no 2 sides parallel used for measuring motor noise; all dimensions in inches**

microphone causes no change in the reading of the output meter, yet it can be heard distinctly in head phones connected in the output circuit of the noise meter. In general, the output meter needle dances around erratically with little apparent reference to the noises the ear detects faintly filtering into the room. The author seriously questions the suitability of the condenser microphone for measuring the noise from quiet fractional horse power motors in a noisy factory, no matter by how much "sound proof" insulation the microphone is surrounded.

A crystal microphone was tried by inserting a microphone head of that type in place of the regular condenser head. The crystal microphone was 14 decibels more sensitive than the condenser microphone at 1,000 cycles, but only 8 decibels more sensitive at 120 cycles. The effect of this difference in sensitivity at different frequencies was to give the over-all response of the meter an equivalent weighting network corresponding to the 40 decibel contour instead of the 50 decibel contour. The results obtained with the crystal microphone were, in general, somewhat the same as with the condenser microphone, and but little more encouraging. Its performance at low noise levels was quite unsatisfactory. In general, it gave the same results as the condenser microphone so far as total-noise measurements were concerned, except of course, slightly lower readings for noises containing prominent low frequency components. Perhaps if less amplification had been used with the crystal microphone, it would have been more satisfactory. Less amplification could have been used because of its greater sensitivity.

The moving coil microphone offers another possibility. Comparative noise tests were made with a Western Electric noise meter which used a moving coil microphone. The moving coil microphone gave a reading at a lower noise level than did the condenser microphone and the needle of the output meter seemed to follow more closely feeble intermittent sounds that were barely audible. It was thought that a part of this difference in performance may have been ascribable to a different weighting network in this meter. Laboratory precision apparatus was not available, but as nearly as could be determined with a beat frequency oscillator and a "photophone" loud speaker, the over-all weighted response of the 2 meters was practically the same at all frequencies. The more plausible explanation, therefore, seems to be that the inherent residual noise of the moving coil microphone is less than that of the condenser microphone, and this, if true, is probably ascribable to its greater sensitivity and consequent less need of amplification. In general the agreement between the noise meters was within 1 or 2 decibels for several different motors, a vacuum cleaner, and an electric drill, provided the microphones were not nearer than 1 foot to the source of noise.

A most serious objection to this moving coil microphone, however, was its sensitivity to stray magnetic fields. With the microphone as far as 2 inches away from a motor, the stray fields of which were negligible from the standpoint of motor performance, the stray fields caused the microphone to indicate 15

to 20 decibels too high, an obviously intolerable error. If the moving coil microphone can be shielded successfully from stray magnetic fields without affecting its acoustic properties, it might be very successful for this application.

*The Weighting Network.* The high noise levels observed with the condenser and crystal types of microphones might have been charged to an improper weighting network for measuring low intensity sounds. The fact that the crystal microphone weighted out the low frequency tones more than did the condenser microphone, but had approximately the same noise level as the latter, and also the fact that the meter with the moving coil microphone apparently had about the same weighting network as the meter with the condenser microphone, would appear to rule out this deduction.

Choice of a suitable weighting network is an important problem. The ideal sought is to select the one that gives, for the largest number of motors, a response most nearly approaching the loudness level that would be determined by the average of a large number of observers by direct aural comparison with a 1,000 cycle reference tone. One way of deciding upon such a network would be to take an acoustic spectrum and select that contour that was most closely approached by the largest number of components of the spectrum.

# Efficiency Tests of Induction Machines

**Several different types of tests for the efficiency of induction machines are discussed in this paper, and results obtained by the different methods are compared. The procedure involved in making the different types of tests is given in detail. In the determination of losses, special attention is given to the stray load loss, which, in most previous tests, has not been considered.**

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THE determination of efficiencies for induction machines has been a debated subject in the A.I.E.E. since its organization. Papers (see references at end of this paper) have been presented and discussed from time to time, but the Institute has not considered the measurement of stray load loss of sufficient importance, or the means available for their measurement sufficiently accurate, to warrant the inclusion of these losses in the calculation of efficiencies. Thus the rules of the Institute have for many years read as follows:

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9–301. Methods of Determining Efficiency Recognized.* The following methods of determining efficiency are recognized as standard:

(*a*) Directly Measured Efficiency: The efficiency is obtained from simultaneous measurements of input and output.

(*b*) Conventional Efficiency: The efficiency is obtained from the component losses, most of which are accurately determinable and the remainder of which are assigned conventional values; or all of the losses may be determined by conventional methods of test. The efficiency determined in this way is the ratio of the output to the output plus the losses, or of the input minus the losses to the input.

* In other than small machines determinations of efficiencies by (*a*) are impractical unless resort is made to expensive measurements.
The use of the conventional efficiency is recommended. Most of the losses are accurately measurable. Those to which conventional values are assigned are so closely approximated that the percentage of error in the determined efficiency is small. The high efficiency generally attained in electrical machines renders an error in the measurement or estimation of one or more of the losses of much less effect on the efficiency as obtained by the conventional method than would an error of like magnitude in the measurement of the total input or output.

9–308. Losses to Be Considered. Conventional efficiencies shall be based upon the following losses:

(*a*) $I^2R$ losses in windings (See 9–310)

(*b*) Friction, windage, and core losses, including brush friction (when present). (See 9–311)

(*c*) Brush contact loss. (See 9–312)

(*d*) Stray load losses. (See 9–313)

(*e*) Miscellaneous losses. (See 9–314)

9–313. Stray Load Losses.* In induction machines no allowance for stray load losses shall be included.

* Stray load losses are inconsiderable in machines of modern design having primary conductors of small section. If the primary windings contain conductors more than $^3/_8$ inch in depth in a 60 cycle machine, eddy current losses may be appreciable. See A.I.E.E. TRANSACTIONS, volume 32, 1913, pages 423–37.

At the time this note was written, the only element of the stray load losses in an induction machine that was well understood was the eddy current loss in the armature copper, but for some time it has been realized that this component is small compared to the increased iron loss under load. The great improvement in the efficiency of pumps and other mechanical equipment in recent years has created a demand for higher and more accurate induction motor efficiency values, and, therefore, committees of the National Electrical Manufacturers' Association and the A.I.E.E. have for some time been conducting investigations to develop an improved technique.

This paper is written to present the results of a series of comparative efficiency tests by different

methods on induction machines made with the specific purpose of demonstrating the improved technique of testing mentioned.

## Nature of the Stray Load Loss

Although the existence of stray load losses has been recognized, the equipment, instruments, and especially the technique necessary to determine these losses have not been sufficiently accurate until the last few years. There are now available the results of the researches of a number of engineers, and the development of new methods of accurate measurement of these losses, which are zero at no load but increase with the load.

The stray load loss is defined as the difference between the actual total power losses under load conditions and the sum of the load $I^2R$ and the no load losses. The elements of the stray load loss (see "Power Losses in Induction Machines," by P. M. Narbutovskih, ELECTRICAL ENGINEERING, volume 53, Nov. 1934, p. 1,466–71) may be classified as follows:

*a.* Changed core loss and high frequency rotor $I^2R$ loss due to changed magnetic fields.

*b.* Increased eddy losses in conductors.

*c.* Increased eddy losses in structural parts.

Item *a* is the only important factor in moderate sized motors in common use.

## Methods of Measuring Efficiency

Five methods have been proposed for the measurement of efficiencies:

*a.* By accurate dynamometers especially designed for this purpose.

*b.* By loading one machine on a directly coupled duplicate machine, accurately measuring the electrical input and electrical output. This pump back test can also be made on duplicate machines connected by belts, but the difficulty of determining the belt loss makes the directly coupled method preferable.

*c.* By separately measuring the various losses and adding them to the output to obtain the input or subtracting them from the input to obtain the output.

*d.* By loading on a calibrated load machine.

*e.* By the calorimetric method of measuring the heat carried away by the cooling medium.

Methods *d* and *e* will not be considered further in this discussion due to their special character.

**Table I—Dynamometer Test**

| | Test Reading | Corrected Readings |
|---|---|---|
| Watts input | 610 | 610.5 × (40 × 0.997) |
| Pounds torque | 76 | 76.35 |
| Rpm slip | 21.3 | 21.3 |
| Frequency | 60 | 59.99 |
| Amperes | 3.63 | 3.63 × (20 × 0.997) |
| Volts | 220 | 220 |
| Input running light coupled | | 1,268 |
| Input running light uncoupled | | 664 |
| Actual load supplied by dynamometer running light | | 604 watts |
| Actual scale reading running light, 1.79 pounds = | | 534 watts |
| Dynamometer error | | 70 watts |
| Motor output = $\frac{76.35 \text{ pounds} \times 1.75 \text{ feet} \times 1{,}178.7 \text{ rpm}}{7.04} + 70$ = | | 22,440.6 |
| Total input = 610.5 × (40 × 0.997) | | = 24,346.7 |
| Total losses | | 1,906.1 |
| Meter losses | | 21.5 |
| Motor losses | | 1,884.6 |
| Efficiency | | 92.25% |
| Horsepower | | 30.08 |
| **Segregation of Losses** | | |
| Core loss | 465 | |
| Windage and friction | 125 | |
| Stator $I^2R$ ($W_1$) | 630 | |
| Rotor $I^2R$ ($W_2$) | 410 | |
| Total known losses | 1,630 | |
| Stray load losses = 1,884.6 − 1,630 = 254.6 | | |

**Table II—Proposed Dynamometer Test**

| | Test Reading | Corrected |
|---|---|---|
| Input (motor) | 612 | 617 × (40 × 0.997) |
| Output (generator) | 520 | 523.5 × (40 × 0.997) |
| Total losses | 92 | 93.5 × (40 × 0.997) |
| Volts | 220 | 220 |
| Amperes (motor) | 3.65 | 3.65 × (20 × 0.997) |
| Amperes (generator) | 3.27 | 3.27 × (20 × 0.997 |
| Slip (motor) | 1.83% | |
| Slip (generator) | 1.54% | |
| Total measured losses = 93.5 × (40 × 0.997) = | 3,729 | |
| Meter losses = | 43 | |
| 2 × (dynamometer error) = | 140 | |
| Total motor and generator losses | 3,546 | |

| Segregation of Losses | Motor | Generator |
|---|---|---|
| Core loss | 465 | 465 |
| Windage and friction | 125 | 125 |
| Stator $I^2R$ ($W_1$) | 640 | 515 |
| Rotor $I^2R$ ($W_2$) | 431 | 338 |
| Total known losses | 1,661 | 1,443 = 3,104 |
| Total measured losses | 3,546 | |
| Total known losses | 3,104 | |
| Total motor and generator load loss | 442 | |
| Motor load loss | 248 | |
| Motor known loss | 1,661 | |
| Motor total losses | 1,909 | |
| Efficiency | 92.25 | |
| Horsepower | 30.4 | |

## Procedure Followed in Making Tests

For purposes of comparison, motors rated 30 horsepower, 1,200 rpm, 3 phase, 60 cycles, 220 volts, were selected and were tested in succession by methods *a*, *b*, and *c*.

*Method (a).* For method *a* the dynamometer was rated 100 horsepower, 1,050 to 3,500 rpm. The dynamometer pull was measured by means of a standard lever and weight system scale connected to a lever arm of 1.75 feet. The motor was directly coupled to the dynamometer and loaded to 30 horsepower at rated voltage and frequency. When temperature conditions became constant, readings were taken of watts input, slip in revolutions per minute, pounds torque as indicated on dynamometer scale, frequency, volts, and amperes. In order to obtain the amount of load supplied by the dynamometer but not indicated on the scale—sometimes referred to as the dynamometer error—readings were made of the following:

1. Dynamometer scale and watts input to the motor with the dynamometer armature and field open.

2. Watts input to motor uncoupled from the dynamometer.

With no dynamometer error the scale reading converted to watts would exactly equal the difference in input readings noted under 1 and 2.

All the meters, instrument transformers, and dynamometer scale used in making the above observations were then checked against laboratory standards to determine correction factors. The results are indicated in table I.

*Modification of Method* (*a*). The above procedure conforms to the proposed "Test Code for Polyphase Induction Machines" of the A.I.E.E. For reasons which will be made obvious in the discussion given later in the paper, the following procedure is recommended for the dynamometer test:

At conditions of constant temperature rise and desired horsepower output, make readings of watts input, voltage, current, slip, and speed. Then without disturbing the setting of dynamometer scale, and holding constant speed and voltage, reduce the frequency of the motor power supply until the dynamometer scale again becomes balanced, and read watts output, amperes, and slip. Determine dynamometer error as outlined above. Results of this method are given in table II.

*Method* (*b*). For method *b*, 2 exactly duplicate motors were coupled together. The machine run as a motor was excited with rated voltage and frequency, and the generator at rated voltage and a frequency sufficiently below rated frequency to give full load input to the motor. When constant temperature conditions were reached, readings were made of watts input and output, motor and generator amperes, and slip. These readings were then repeated with the power flow reversed—that is, the machine that was first a motor became a generator and *vice versa*. The machines were then shut down and hot resistance readings taken. Finally, an excitation curve was taken on each motor coupled to the other. See table III for results obtained with this method.

### Table III—Pump Back Test (Coupled)

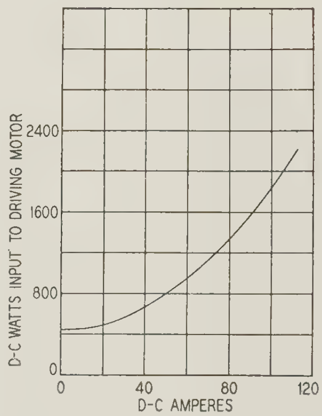
| | Test Reading (Avg. 2 Directions) | Corrected |
|---|---|---|
| Input | 613 × (40 × 0.997) | 24,446 |
| Output | 523.6 × (40 × 0.997) | 20,881 |
| Total losses | 89.4 × (40 × 0.997) | 3,565 |
| Motor slip | 1.83% | 1.83% |
| Generator slip | 1.54% | 1.54% |
| Motor amperes | 3.65 × (20 × 0.997) | 72.8 |
| Generator amperes | 3.28 × (20 × 0.997) | 65.4 |
| Motor resistance, hot | 0.08 | 0.08 |
| Generator resistance, hot | 0.08 | 0.08 |

**Segregation of Losses**

| | Motor | Generator | |
|---|---|---|---|
| Core loss | 465 | 465 | |
| Windage and friction | 125 | 125 | |
| Stator $I^2R$ ($W_1$) | 640 | 515 | |
| Rotor $I^2R$ ($W_2$) | 428 | 338 | |
| Total known losses | 1,658 | 1,443 | = 3,101 |
| Total measured losses | = 3,565 | | |
| Meter losses | 43 | | |
| Total motor and generator losses | 3,522 | | |
| Total known losses | 3,101 | | |
| Total stray load loss | 421 | | |
| Motor stray load loss | 235* | | |
| Motor known losses | 1,658 | | |
| Motor total losses | 1,893 | | |
| Efficiency | 92.25 | | |
| Horsepower | 30.2 | | |

* $\frac{W_2 \text{ Motor} \times \text{Total Stray Load Loss}}{W_2 \text{ Motor} + W_2 \text{ generator}}$

*Method* (*c*). For method *c* the motor was directly coupled to a small d-c motor rated 8.5 horsepower, 14.5 amperes, 230 volts, 600/1800 rpm. (See table IV.) Two lines of the stator winding were excited with d-c and the motor driven at synchronous speed. Readings were taken of driving motor armature volts and amperes, holding constant field current, for values of d-c excitation from zero to 150 per cent equivalent, full load a-c current. (See figure 1.)



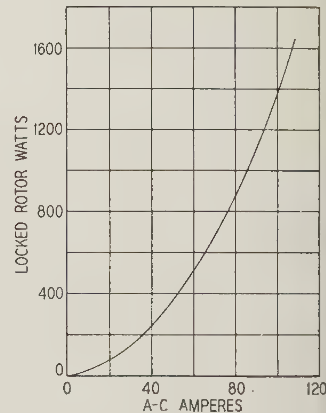




**Fig. 1 (left). D-c rotational watts input to the driving motor used in the direct measurement of losses in an induction motor**

**Fig. 2 (right). Locked rotor synchronous watts as determined in the method of direct measurement of losses in an induction motor**

To determine the 60 cycle rotor loss, starting torque was measured over these current ranges. (See figure 2.)

A comparison of the results obtained in other tests conducted by methods *a*, *b*, and *c* is given in table V.

## General Discussion

*Method* (*a*). The dynamometer method has usually been considered the most convenient for machines of about 100 horsepower or less where suitable dynamometers and instruments have been available. It has been favored by many users because only one machine to be tested is necessary as well as a single source of controlled power, and a minimum of measuring instruments. It also gives the most directly calculated measurement of efficiency. However, there are a number of details involved in power measurement that are not generally appreciated. To begin with, a wattmeter connected *directly* in a power circuit will read the power consumed by either its voltage or current coil (depending upon the method of connection) in addition to the power it is desired to meter. A General Electric type $P_3$ polyphase wattmeter voltage coil at 220 volts consumes

about 7 watts, so that in the common hook-up for measuring power there will be at least 21 watts instrument losses. If current and potential transformers are used, the wattmeters will read the losses on *one* set of these also. When instrument transformers are used, calibrations must be available for both ratio and phase angle displacement. All of these points must be considered in addition to the calibration of the wattmeter scale itself. Furthermore, the accuracy to which an instrument can be read is dependent upon the scale deflection, the steadiness of the needle, and the ability of the observer to read what the instrument indicates. This last point is quite important, for it is not uncommon to find observers who consistently read instruments higher or lower than their true indicated values.

The measurement of mechanical power is equally difficult. There are 2 measurements, torque and speed, each bearing directly on the power. The pounds pull exerted by the dynamometer is usually measured by means of either a spring or link scale, the pull being exerted through a lever arm of definite length. In conjunction with the calibration of the scale, the dynamometer sensitivity is important. This is the amount of weight required to give a readable deflection of the dynamometer scale; that is, the weight required to overcome the static friction of the trunnion bearings. Dynamometers (see "Modern Equipment for the Precise Testing of Motors," by A. A. Emmerling, *General Electric Review,* volume 37, Oct. 1934, p. 471–6) may be equipped with a mechanism which continually oscillates the intermediate races of specially designed trunnion bearings, which has the effect of increasing the sensitivity about 50 times. The recommended method of determining speed involves the measurement of both frequency and slip. Slip may be measured quite accurately and easily by means of a differential slip meter. Frequency, however, must be determined to less than 0.1 per cent, requiring at least a specially calibrated device capable of indicating this closely.

The dynamometer also must be checked for failure of its scale to indicate all the load applied. Finally, readings of input and output must be made simultaneously. The limiting features of this method are: (1) the number of readings, pertaining directly to the efficiency, which must be determined with almost perfect accuracy; (2) the restriction of size and rating of the motors that may be tested on a given dynamometer, and the resulting large investment in dynamometers necessary if the method is to be given wide use.

*Modification of Method* (*a*). The modified procedure suggested for conducting the dynamometer test overcomes most of these objections. Although the same accuracy is required of the instruments measuring electrical power, by reversing the power flow certain of the contributing sources of error may be eliminated. If the observer tends to read an instrument high, his observations will be high for both motor and generator readings, thereby minimizing the error in the difference. Similarly, if a current or potential transformer ratio is in error, both the input and output readings will be high or low by the same percentage. Exact frequency measurement is not necessary as neither the input nor output is a direct function of speed. Variations up to about one per cent in frequency have little effect on efficiency. There are only 2 measurements bearing directly on the efficiency.

The only measurement of mechanical power necessary is in the determination of the "dynamometer error." The difference between the watts input and output by this method will be the losses of the machine as a motor and generator plus 2 times the dynamometer error:

Motor input − motor losses = dynamometer scale + dynamometer error

Generator output + generator losses = dynamometer scale − dynamometer error

Input − output = losses (motor + generator) + 2 × (dynamometer error)

Since the dynamometer error is always a very small percentage of the total power, inaccuracies in determining the mechanical power used in finding this error will produce little effect on the results obtained by this method.

There may be a minor source of error in the segregation of losses. From investigation of numerous tests, it has been shown conclusively that the stray load loss is a direct function of the load current squared, or slip loss; so it is reasonable to assume that this holds between motoring and generating action.

It has long been felt that, when a dynamometer test is made on a motor, it is very desirable to make a check test as a generator, in order to check the measurement of mechanical power against electrical power. This proposed procedure provides for that test, while at the same time reducing the effect of error in the measurement of mechanical power to one of the second order magnitude.

*Method* (*b*). The procedure for the directly coupled pump back test is analogous to the proposed dynamometer test, so that the pump back test has all the advantages thus noted. It does not have any limitation as to size or rating, however, as exactly duplicate machines must be available. It should be noted that the pump back method does not give the efficiency for one machine, but rather the average of 2 machines running as a motor. A major point in favor of testing by this method is the minimum amount of investment in testing equip-

### Table IV—Direct Method

Full load current = 73 amperes........Running light current = 23.2 amperes

Equivalent direct current:

| | | |
|---|---|---|
| Full load = 1.225 × 73 = 89.3 | | |
| Running light = 1.225 × 23.2 = 28.4 | | |
| Net d-c watts: | | |
| Full load = 1,540 − 440 = | 1,100 | figure 1 |
| Running light = 540 − 440 = | 100 | figure 1 |
| Load loss + rotor $I^2R$ = | 1,000 | |
| Rotor $I^2R$: | | |
| Full load = | 740 | figure 2 |
| Running light = | 74* | figure 2 |
| | 666 | |
| Stray load loss = 1,000 − 666 = 334 | | |

* Since the value of torque on figure 2 at running light current is inaccurate, the value for this point is obtained by multiplying the torque for full load current by the ratio $(I_{RL}/I_{FL})^2$.

Table V—Comparison of Results of Other Tests by the 3 Methods

| Motor | HP | Speed | Type | Full Load Efficiency by Method (a) | (b) | (c) |
|---|---|---|---|---|---|---|
| *A* | 10 | 1,200 | S.C. | 84.6 | 84.6 | |
| *B* | 10 | 1,200 | S.C. | 87.2 | 87.3 | |
| *C* | 10 | 1,200 | S.C. | 82.3 | 82.4 | |
| *D* | 30 | 1,200 | W.R. | | 88.1 | 88.1 |
| *E* | 50 | 1,800 | S.C. | 91.9 | | 91.7 |
| *F* | 25 | 1,200 | S.C. | 89.72 | | 89.7 |
| *G* | 125 | 1,200 | W.R. | | 92.7 | 93.1 |
| *H* | 15 | 1,200 | S.C. | 86 | | 86.35 |
| *I* | 15 | 1,200 | S.C. | 86.07 | | 86.2 |
| *J* | 50 | 1,800 | W.R. | 89.3 | | 88.3 |

Note: S.C. = squirrel cage
W.R. = wound rotor

ment since, in most cases, adequate sources of power and instruments are available.

*Method* (*c*). The d-c method presents the one advantage that it may be applied to any single motor irrespective of size or rating. The d-c rotational watts may be determined accurately by the method outlined. In the case of squirrel cage machines, however, the determination of rotor $I^2R$ loss presents a rather difficult problem, especially if the motor bearings have high static friction. In this case, it may be necessary to measure the starting torque at current values considerably higher than normal. There should be no limit to the value at which this may be taken other than heating. On some machines, if the rotor heating is excessive the value of starting torque watts may be considerably higher than those existing in the machine under the d-c test. As there is no absolutely positive way to determine when these losses are the same for the 2 conditions, the decision must be left solely to judgment. Tests indicate that errors resulting from heating may be considerably less than those arising from the situations in which the static friction torque is equal to or greater than the losses to be measured.

The d-c method similates load conditions in so far as they affect stray load loss without actually producing full load torque on the shaft. In the case of wound rotor induction motors, the test is a parallel of the synchronous motor short-circuit test, which has long been approved as a standard.

## General Recommendations

The results of tests as given in this paper, and the information obtained from a large number of other tests made during the past few years indicate that first 2 of the test methods considered give the same results, if proper equipment is available, and due care is taken in testing, calibration, and calculation. It is concluded that both methods are satisfactory for use in the standards for determining efficiency guarantees. Which method is to be preferred, therefore, depends upon the accuracy expected with the available equipment, and the cost of making the test, rather than upon any differences in the inherent accuracy of the method.

For small or moderate sized machines up to about 100 horsepower rating, and particularly when only one machine is available for test, the dynamometer method may be the most convenient and is to be recommended. However, too great stress cannot be laid on the necessity for extreme care in making test readings, calibrations, and calculations; and the desirability of making check generator and motor tests should be remembered.

Where 2 duplicate machines are available, the electrical pump back method is most convenient, and affords greater accuracy with less probability of error than the other methods. Check tests with the power flow reversed are assumed to be a standard procedure in this test. With proper power supply and equipment available, this method is to be preferred to the other methods for all sizes of machines of ratings of above about 10 horsepower.

For single machines of larger sizes, the separate loss method, determining the stray load loss with d-c excitation, is often the only method practical, as large dynamometers are not available, and in unusual cases, adequate power supply may not be obtainable. This method does not exactly duplicate actual load conditions, but tests have shown that results obtained are a measure of the actual stray load loss. In other words, while these values are not exactly the same as those obtained by methods *a* and *b*, they are of the same order of magnitude. There is not enough comparative data available to draw definite conclusions as to its relative accuracy, therefore it should be preferred only when the other methods are not available.

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# Multiple Lightning Strokes

**Multiple lightning strokes have long been known to exist, but so far instruments for recording the successive discharges on electric power lines have not been available. The application of expulsion protective gaps to 3 typical transmission lines, however, has made a partial investigation possible, with the aid of the automatic oscillograph. The results of this investigation are presented herewith. As many as 12 successive discharges have been recorded in a single stroke; these discharges have been as close together as 1 cycle (on a 60 cycle system) and as far apart as 9.5 cycles.**

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LIGHTNING itself still remains the major unknown in the problem of protecting electric power lines from lightning. Sufficient information is available to make what are believed to be reasonable assumptions, but the wave shapes of lightning itself, magnitudes, and frequency of occurrence of each form still are unknown. The existence of multiple strokes has long been known, but no record of their occurrence has been obtained from the instruments in use during the lightning investigations of recent years.

The operation of expulsion protective gaps on 3 typical transmission lines, together with oscillographic means of registering the follow currents over a period of approximately 1 second have shown about 20 per cent of the lightning strokes on 2 of the lines to consist of successive discharges. The maximum number recorded was 12, occurring in about $^2/_3$ of a second. The effect of successive discharges on insulation, gaps, and protective apparatus must be determined before the importance of the multiple stroke can be evaluated.

Data obtained on these 3 lines show that successive discharges may occur as close together as 1 cycle of a 60-cycle system, and as far apart as 9.5 cycles. Additional data no doubt will extend these values. The data show also that many more expulsion gaps flashed over when the conductor was positive than when negative. It is suggested that the power frequency potential plays an important rôle in determining which conductor will be flashed. Tests simulating a direct stroke to a tower show that the polarity of the line conductor exhibits a marked effect on which conductor is to flash over. If the lightning is severe enough, of course, all conductors will flash.

Full text of a paper recommended for publication by the A.I.E.E. committee on transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. *Not published in pamphlet form.*

1. For all numbered references see list at end of paper.

## Review of Previous Work

Much progress has been made in recent years in the determination of the effects of lightning on transmission lines and apparatus. Field studies[1,2,3,4,5] have yielded much information concerning the magnitude of voltages appearing on transmission lines, and the frequency of their occurrence. The propagation of impulses over lines[6,7,8,9] has been studied by the use of the portable cathode ray oscillograph and impulse generator. From these studies, coupled with other field tests with natural lightning, the decrease in crest potential and change in wave shape with travel now are known reasonably well. Calculations[10] now may be made with confidence concerning the effect of various terminal impedances on the shape of traveling waves of known shape.

Field tests[11] have been made with applied impulses showing the effect of lightning arresters under various conditions, both on high potential circuits and on low potential distribution circuits. The necessity of adequately grounding transmission line towers to prevent insulator flashover when a tower or ground wire is struck has been recognized, and field[12,13] tests have been made to determine the effect of various factors entering into this problem. The foregoing is but a very brief résumé of some of the accomplishments of recent years; but, it is clear to one who has followed technical literature on this subject that the major variable, still largely unknown, is the lightning discharge itself. Once the characteristics of lightning are known, including voltage, current, and time relations, and frequency of occurrence, it will be possible to put the problem of protection from lightning on a better basis than is now possible.

Field investigations have been conducted during recent years, having as their object the determination of the wave shape of the potential of the lightning discharge. Data on wave shape were obtained through the use of cathode ray oscillographs coupled to transmission lines. These have yielded valuable information but in only one instance[14] reported in the United States was the lightning discharge close to the oscillograph. In every other instance the discharge traveled for considerable distances over the line wires, suffering changes in magnitude and wave shape. In addition, the record frequently is complicated by flashovers, which allow unknown amounts of current to pass to the earth. Thus, it can be seen that much still remains to be done, as there is not available a cathode ray oscillogram that shows the form of the lightning discharge itself without accompanying flashover.

Much valuable field work has been done, and is still in progress, having for its object the determina-

tion of currents associated with direct strokes of lightning. Measurements have been made by various means, but probably the most reliable data have been obtained recently through the use of the surge crest ammeter.[5] The results thus obtained will be most helpful, since the data give both magnitude and frequency of occurrence as between storms, if the magnets of the instrument are checked after each storm. No information, however, is obtained concerning the number and magnitude of discharges during a given storm, except that a record is obtained of the maximum current if all the polarities are the same. The magnets do not give any indication of wave shape.

### Records Obtained With Rotating Camera

It has been known for many years[15] that many lightning discharges are multiple in character—each succeeding discharge following closely the path of the preceding discharge. As many as 40 discharges in 0.624 second have been recorded by the use of the rotating camera.[16,17]

Recently, Dr. B. F. J. Schonland and H. Collens[18] of South Africa, using a modified Boys camera, have shown that each of the multiple strokes is preceded by a leader stroke that proceeds from the cloud to the earth, to be followed by the main flash building up from the earth to the cloud. The leader, which precedes the first flash, has been called a stepped leader, and appears to travel in the form of a dart toward the earth in a series of steps. The rate of travel is relatively slow, perhaps of the order of $^1/_{10}$ of the speed of the subsequent leaders which apparently travel at about 0.1 to 0.01 of the speed of light. These results have been confirmed in Pittsfield by Lloyd and McMorris.[19] The path of the main flash and subsequent flashes is determined by the stepped leader.

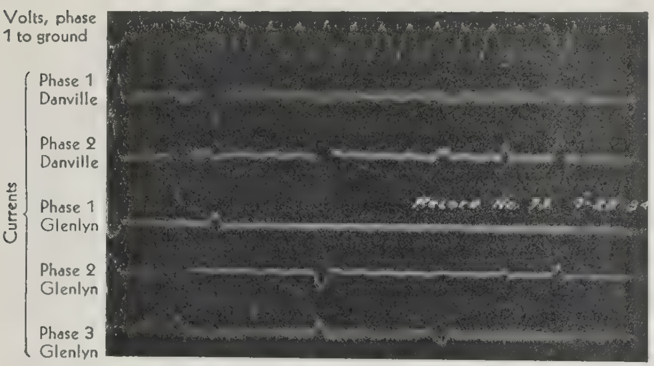


**Fig. 1. Typical crater lamp oscillogram taken on the Roanoke-Danville and -Glenlyn (Va.) lines showing operation of expulsion protective gap on successive lightning discharges (first half cycle retouched)**

It is important to understand the mechanism of lightning in order that its action may be understood. There seems to be considerable evidence that lightning does not always strike the highest object. In fact, there is evidence to show that steel buildings have been struck part way down the vertical surface, and occasionally steel masts have been struck below the top. Apparently, local ionization may have considerable influence in directing lightning strokes, and it is with this thought in mind that investigators[20] have been trying to determine the relation between sources of ionization on the earth's surface and the location of lightning strokes. The evidence of protection[21] obtained from large numbers of lightning rods indicate that the highest object usually is struck, perhaps 95 or more per cent of the time; but if perfect protection is to be obtained, the Faraday cage must be resorted to rather than depending upon a cone of protection. For many uses the Faraday cage is not practical.

### Multiple Strokes

Heretofore, it has not been possible to secure data concerning the existence of multiple strokes on transmission lines. The maximum time scale of the cathode ray oscillograms taken did not exceed 1,000 microseconds, which was much too short to record the multiple stroke, and, so far as the writer is aware, none ever were recorded. The other devices used in the field investigations of natural lightning could not show clearly the presence of multiple strokes.

The application of expulsion gaps to the 132 kv Glenlyn-Roanoke (Va.) and Roanoke-Danville (Va.) lines of the American Gas and Electric Company and to the Laurinburg-Wilmington (N. C.) 110 kv line of the Carolina Power and Light Company made a partial investigation of direct strokes possible. Heretofore, when a line flashed over, the follow current to ground obscured the effect of any subsequent multiple flash, and thus no evidence was obtained. However, here was an opportunity to secure some valuable data, since the expulsion gap allows power current to flow for only $^1/_2$ cycle, and a subsequent multiple flash occurring at a greater time interval than $^1/_2$ cycle would leave a record of its existence on the ordinary automatic magnetic oscillograph. Fortunately, automatic oscillographs were available to indicate fault current on each system.

However, the record would be incomplete without the first half cycle, and since most of the discharges might be single and not multiple strokes, it became apparent that means must be found to record the first half cycle of fault current. This was accomplished at Roanoke through the use of the crater lamp oscillograph[22] built especially for this use. With this oscillograph, the film is kept running continuously during the lightning storm, the light source being a crater lamp which is initiated in about 20 microseconds through "thyratron" control ("thyratron" is a trade name of the General Electric Company and indicates a 3-electrode gas- or mercury vapor filled electronic tube). In many cases, it is possible with this equipment to get a "kick" on the oscillograph vibrator due to the transient before follow current starts. The oscillograph was connected, as described in a paper by Sporn and Gross (scheduled for publication in the January 1935 issue

so as to read fault current in phases 1 and 2 of the Roanoke-Danville line, and in all 3 phases of the number 1 circuit of the Roanoke-Glenlyn line. The sixth vibrator was used to record potential to ground of phase 1 at Roanoke. The automatic type *PM*-13 oscillograph at Glenlyn recorded the fault currents in both circuits of the line to Roanoke. The Roanoke-Glenlyn line is a double circuit line, number 1 circuit being equipped with expulsion protective gaps.

On the Laurinburg-Wilmington line the automatic type *PM*-13 oscillograph was installed at Laurinburg. With this oscillograph, the 110 kv expulsion protective gaps do not leave any record of follow current during normal operation, unless multiple discharges occur, but in 2 cases records were obtained showing the presence of multiple discharges. The data obtained have been included with that from Roanoke, but is identified in each case.

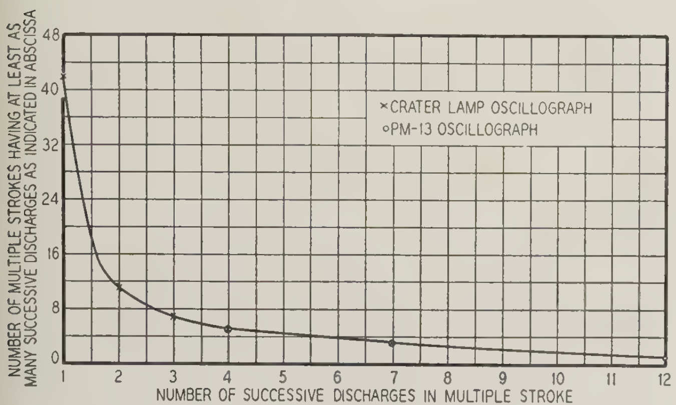


**Fig. 2. Number of successive discharges in multiple lightning strokes**

Data taken with type PM-13 oscillograph from Carolina Power and Light Company system

Record 73 from the Roanoke-Danville line, showing successive discharges, is reproduced in figure 1. This record from the crater lamp oscillograph shows the first tube operation.

## Frequency of Occurrence

Out of a total of 39 recorded strokes obtained on the crater lamp oscillograph at Roanoke (counting multiple strokes as one) 8 or 20 per cent were multiple. These data were obtained from 123 miles of line. On the Carolina system, the total number of strokes is unknown, since only automatic oscillograph records are available. However, on this system 2 records were obtained from $92^1/_4$ miles of line.

There seems to be a definite tendency for some storms to produce more multiple strokes than others. For instance, the records at Roanoke show that on the first 10 days during which strokes occurred a total of 16 strokes was recorded during the time from June 11 to July 19, but none of these were multiple although 5 occurred on one day. However, on July 21 a storm beginning at 3:06 p.m. and continuing for 5 hours yielded 4 multiple strokes and 2 single strokes. Of these 4, 2 consisted of 2 successive discharges each, 1 of 4, and 1 of 3 discharges. Four days later a 2 hour storm beginning at 3:12 p.m. delivered to the lines under observation 9 single strokes, 1 of 2, and 1 of 3 successive discharges. Three single strokes were recorded during the storm of July 26, while on July 28 only 2 strokes were recorded, both multiple, 1 consisting of 2, and the other of 7 successive discharges. Nearly a month later, on August 24, the next and last record was obtained, being a single stroke.

Thus, in a total of 15 days on which expulsion gaps functioned due to lightning, multiple strokes were measured on only 3 days, but during these 3 days, 8

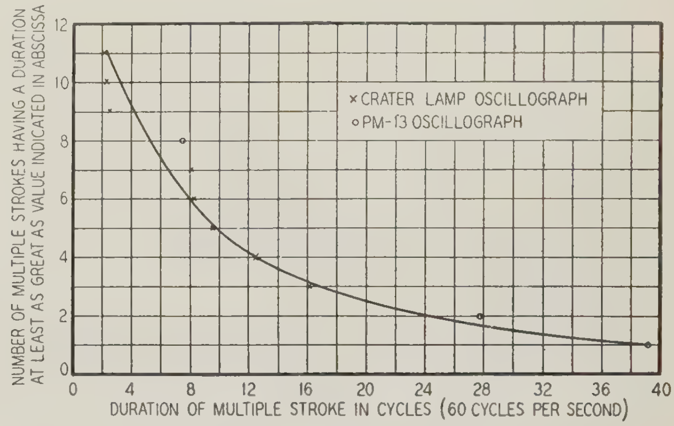


**Fig. 3. Total duration of multiple lightning strokes**

Data taken with type PM-13 oscillograph from Carolina Power and Light Company system

out of 19 or 42 per cent were multiple. During these 3 days, a total of 36 discharges occurred, of which 25 were successive and 11 were single discharges.

In the foregoing, no effort has been made to include records of direct strokes where follow current through the expulsion gap did not take place. No doubt some of the oscillograph operations were due to lightning discharges that did not cause tube operations. Such records are, however, too uncertain to be included, and therefore the results given may be in error to that degree.

## Number and Times of Successive Discharges

Combining all of the data from the 2 systems being studied together, figure 2 shows the relation between the number of successive discharges and the number of times at least that many discharges occurred. Although all of the multiple discharge points are known for the Carolina data, yet the number of single strokes is unknown. Adding these would increase the total number of discharges by an unknown amount. It would not affect the shape of the curve materially. This curve indicates that, as would be expected, the larger the number of successive discharges, the less frequently they occur.

The total time occupied by successive discharge of the multiple strokes is given in figure 3 showing that the longest time was 40 cycles or about $^2/_3$ second.

This compares with 0.624 second obtained photographically by Larsen.

## Time Interval Between Successive Discharges

The time interval between successive discharges is important, as it will determine the characteristics protective devices must have to be always in a condition to offer the same protection for successive discharges as for a single stroke. The time interval also will have an important bearing on the strength of insulation, whether solid or otherwise, required for such conditions as compared with the strength required to withstand a single impulse.

The curve in figure 4 shows that the shortest time interval was 1 cycle and the longest $9^1/_2$ cycles. Thus, it appears that protective devices must be capable of restoring themselves in a time of 1 cycle. Tests made on insulation with equal time intervals of 1 cycle represent a frequency of application higher than these data indicate, and thus would lead to an insulation design incorporating a certain factor of safety. It appears that such a procedure would represent the simplest method of approaching this problem from the testing point of view.

In figure 5 is shown the relation between the number of successive discharges and the time interval between them for those recorded having more than 2 successive discharges. There seems to be some tendency for the time interval to become greater

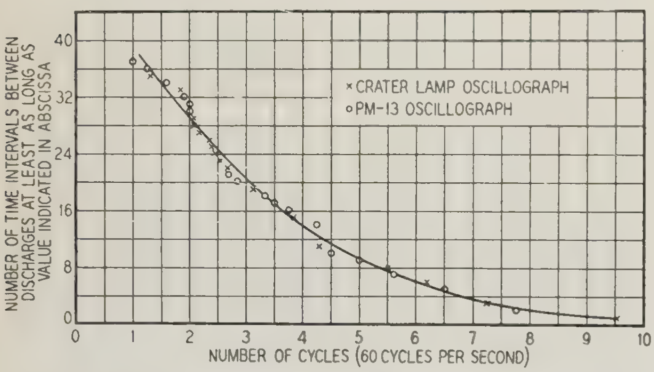


**Fig. 4. Time between discharges in multiple lightning strokes**

after the second discharge, but there is no well defined relationship, the 2 7 discharge strokes showing a decreasing interval after the fifth discharge. Of course these values are confined to strokes causing operations of the expulsion gap, and may not represent all the multiple strokes, which might have been obtained with a moving film camera.

## Effect of Conductor Polarity

On all 3 phases of both circuits there appears to be a definite tendency for expulsion gap operation when the phase potential is positive. Table I shows the results tabulated with respect to polarity. Including all of the successive discharges as separate discharges, follow current began 54 times when one of the phase conductors involved was positive, and 22 times when one of the conductors involved was negative; 7 times the potential was substantially zero. The data show that follow current occurred 32 times with conductors of positive polarity only involved, and 4 times with conductors of negative polarity only involved. This is without respect to whether the conductor is the top, middle, or bottom conductor.

It is suggested that the reason for the expulsion gap operation when the conductor is positive, may well be accounted for largely when it is remembered that the records show most direct strokes to be negative; therefore, the flashover potential of the conductor having the highest positive potential will be reached first, assuming that lightning strikes the tower or ground wire. If after this flashover, sufficient potential still remains, other conductors will flash over, the most positive one tending to flash first. This tendency would be greatest at maximum positive potential, which for the 132 kv circuits out of Roanoke would equal 107 kv crest. This value is somewhat greater than 10 per cent of the 1x5 mi-

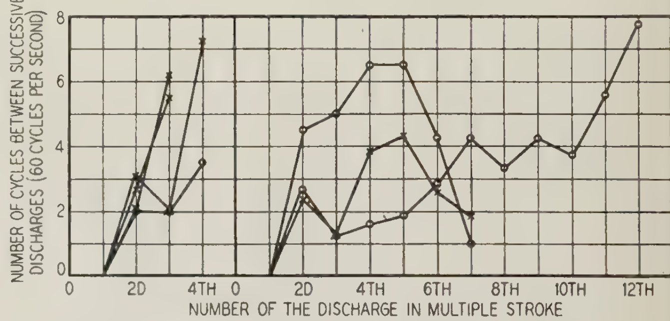


**Fig. 5. Time between successive discharges of multiple strokes having 3 or more discharges**

Curves on left are for strokes having 3 and 4 successive discharges; those on right are for strokes having 7 and 12 successive discharges

x—crater lamp oscillograph; o—type PM-13 oscillograph

crosecond flashover voltage of the insulator string, and often would be sufficient to determine which phase would flash over. The fact that 7 times as many expulsion gap operations occurred when only positive conductors were involved as when only negative conductors were involved seems to give weight to this suggestion.

Laboratory tests made recently in Pittsfield (Mass.) to simulate a positive conductor and negative stroke to the tower indicate clearly that the foregoing explanation offered is plausible. In making the test, 3 suspension insulators were suspended, the ground end being connected to earth through a resistance of several thousand ohms. A potential of 20 kv from a power transformer was applied between the line conductor and the earth. The circuit was so arranged that a negative impulse could be applied to the ground end of the insulator string at either 90 or 270 degrees with respect to the potential on the line conductor. Without power voltage on the string, the impulse flashover was found to be

## Table I—Polarity of Phase Potential When Follow Current Begins

**Multiple Strokes to Danville Circuit**

| Record No. | 40 | 43 | 48 | 49 | 51 | 57 | 72 | 73 | Total per Phase |
|---|---|---|---|---|---|---|---|---|---|
| No. of Discharges | 2 | 2 | 4 | 3 | 2 | 3 | 2 | 7 | |
| Phase 1 | −+ | 0− | +++ | | +− | ++ | + | 0 0 | 8+ 3− 3 zeros |
| Phase 2 | + | ++ | + | ++ | −+ | − − | | ++ + ++ | 12+ 3− |
| Phase 3 | | | | + + | − | − | + | + ++ | 6+ 2− |

**Single Strokes to Danville Circuit**

| Record No. | 1 | 2 | 4 | 7 | 14 | 30 | 31 | 46 | 50 | 53 | 54 | 55 | 56 | 58 | 59 | 60 | 61 | 67 | 79 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase 1 | + | + | + | 0 | − | | | | + | + | + | | + | − | − | + | + | − | + | 10+ 4− 1 zero |
| Phase 2 | | | | + | − | + | + | − | | + | | | − | + | − | | | + | | 6+ 4− |
| Phase 3 | | | | | | | | + | − | − | | + | | | | | − | | | 2+ 3− |

**Single Strokes to Glenlyn Circuit**

| Record No. | 3 | 8 | 10 | 12 | 13 | 23 | 27 | 28 | 38 | 44 | 62 | 64 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase 1 | | + | | 0 | | 0 | | | | | | + | 2+ 2 zeros |
| Phase 2 | | | − | | | + | | 0 | + | − | + | | 3+ 2− 1 zero |
| Phase 3 | + | | + | | + | | + | − | | | + | | 5+ 1− |
| Total | | | | | | | | | | | | | 54+ 22− 7 zeros |

about 350 kv. With a positive potential on the string, flashover took place with 16 per cent reduction in impulse potential, and with the conductor negative it was necessary to increase the impulse potential 13 per cent. Similar results were obtained with a higher power voltage on the insulator string.

It may be argued that negative lightning would be more likely to strike a conductor when positive than when negative. While this may account for some of the records, it would seem as though with this hypothesis the top conductor should have received a larger share of the discharges than it did. The total number of discharges when the conductor was positive was 20, 21, and 13 for the top, middle, and bottom conductors, respectively. No test data are available to show just how important a factor this effect may be. There is nothing in the data to show conclusively whether the line conductors or ground wire were struck; but, based upon general consideration, one would expect the ground wire to receive the majority of discharges because of its more exposed position.

## Summary

1. Multiple strokes occur to transmission lines, and create a series of impulses that may be as close together as 1 cycle or as far apart as 9.5 cycles (on a 60 cycle system). As many as 12 successive discharges were recorded, although photographically 40 discharges have been recorded in a time of 0.624 second.

2. There seems to be a tendency for multiple strokes to be somewhat confined to certain storms, although more data must be obtained before any definite conclusions can be drawn.

3. There seems to be little consistency between multiple strokes as to the time interval between successive discharges.

4. The polarity of the power frequency potential appears to have considerable influence upon determining which conductor flashes to ground. This has been shown experimentally to be expected when lightning of opposite polarity strikes the tower or ground wire. It also may have some influence in determining which line conductor is struck.

5. Since the data obtained show that 20 per cent of the recorded strokes consisted of more than one discharge, the effect of multiple discharges must be considered in any protective scheme. This is true both with regard to the apparatus to be protected and the protective apparatus itself.

6. More data is needed concerning the multiple stroke so that good engineering estimates of its importance and effects can be made. It is expected that this investigation will be continued.

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# Impulse and 60 Cycle Strength of Air

The effect that the shape of electrodes has on the dielectric strength of air when subjected to impulse and 60 cycle voltage waves is considered in this paper. Principal attention is given to rod and plate electrodes and to sphere and plate electrodes, comparative data on the different types being given. Among other factors, the effect of polarity on breakdown voltage is brought out. These data on strength of air between various electrode shapes are correlated into working principles and presented from the standpoint of the design engineer interested in their application.

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AIR is universally used in high voltage engineering, such as for the insulation of transmission lines, substation structures, coördination and protective apparatus, bushings, and in fact even for the insulation of complete electrical apparatus. Hence the paramount importance of air as a dielectric is manifest; this accounts for the many endeavors in the past to establish the strength of air on a reliable basis. The inconsistencies and variations between the results of various investigators is another reason for the repeated efforts in the past to obtain reliable data on the strength of air. The following considerations account for the incomplete reliability of a great deal of the past data for application to design work in high voltage engineering: First, the technique of voltage testing[1,2,3] and measurement[4–7], particularly with impulses, had not been established on a reliable and practical basis until in recent years. Second, the effect of such factors as air density, pressure, humidity, etc., on the strength of air to impulse[8,9] and 60 cycle[10–12] voltages have been formulated lately to a degree of accuracy that better comparison of data obtained in various laboratories is now possible.

Many investigators have studied the strength of air,[13–19] particularly from a fundamental standpoint.[13–16] Some of the published data is limited to relatively short gaps. Of these data, a great deal is difficult to interpret and consequently to apply to design, simply because testing conditions, air density (temperature and atmospheric pressure), humidity, etc., are either not fully specified or more often not mentioned at all. Nevertheless some data particularly for 60 cycle strength for wide gap openings is found in the literature which are useful for design application, though the desired detail information of test and atmospheric conditions may be lacking. A systematic effort has been made lately[20–22] to standardize the technique of testing and measurement and to establish reliable correction factors which, all combined, will aid in making published data in the future of greater usefulness.

In the investigation reported here full advantage was taken of the latest technique in testing and measurement, as well as in the application of correction factors wherever it was deemed essential to refer the experimental data to unity air density (25 degrees centigrade temperature and 760 millimeters barometric pressure) and standard humidity (6.5 grains per cubic foot). Impulse and 60 cycle voltages ranging up to 2,000 kv have been investigated as these comprise the voltages which are commonly encountered in present everyday practice. Thus data on strength of air between various electrode shapes and arrangements that are of fundamental importance in high voltage engineering are presented in this paper. To render the experimental results more useful, the data are correlated into working principles, thus aiming to show that the

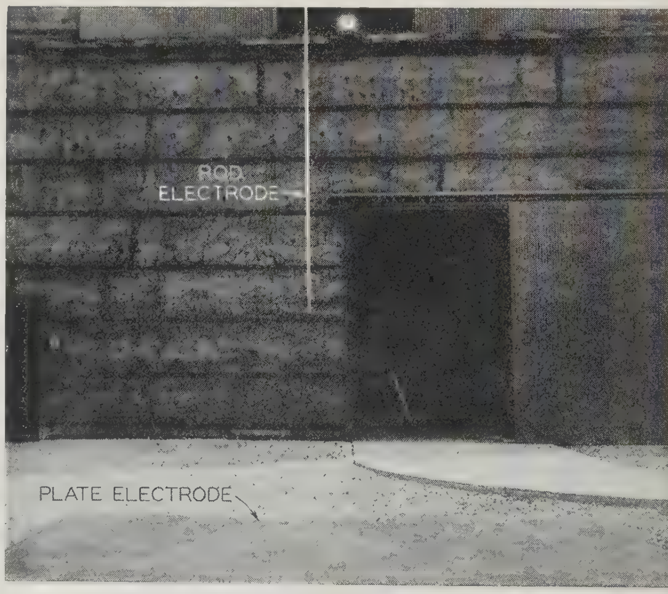



**Fig. 1. Rod-to-plate gap**

0.5 inch square cut, square rod; 0.25 × 120 × 170 inch plate

Full text of a paper recommended for publication by the A.I.E.E. committee on electrical machinery, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 15, 1934; released for publication Nov. 1, 1934. *Not published in pamphlet form.*

1. For all numbered references see list at end of paper.

fundamentals of high voltage engineering are susceptible of being established on a more systematic basis.

The results of this investigation are therefore presented from the standpoint of the design engineer whose particular concern is the immediate application of working principles to the economical development of electrical apparatus which must perform according to required characteristics. However, the writers realize that the data on the strength of air now made available offer great opportunities for studies on the mechanism of breakdown in gases to account for, explain, and, if possible, even to formulate the phenomena observed. Such a study is, however, beyond the practical realm of the present paper.

The first part of this paper deals with the impulse and 60 cycle strength of air for rod and plate electrodes whereas in the second part the impulse and

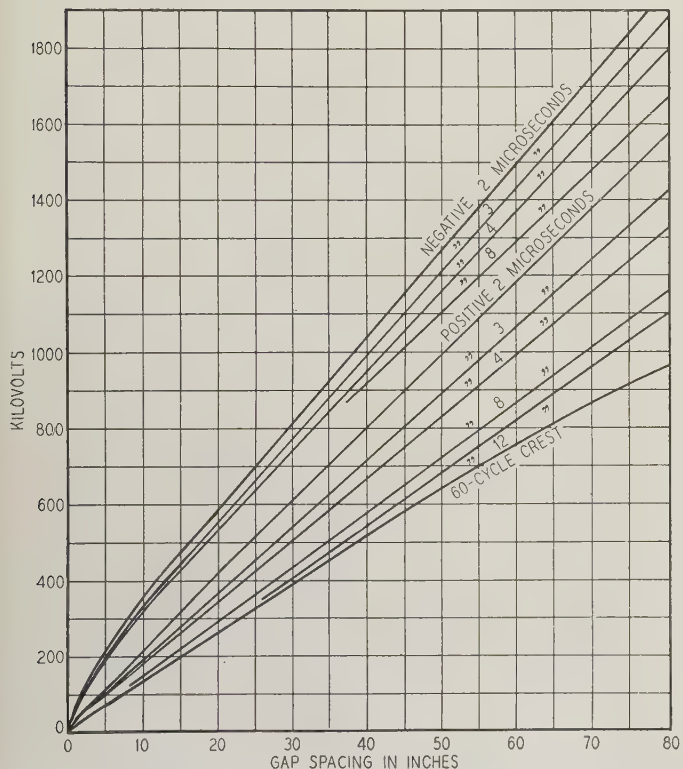



**Fig. 2. Positive and negative impulse voltage characteristics of rod-to-plate gap**

Relative air density = 1.00; absolute humidity = 6.5 grains per cubic foot

60 cycle strength of air between sphere and plate electrodes is given. The following conclusions summarize the pertinent facts on the strength of air as affected by shapes of electrodes.

## Conclusions

1. The effect of polarity on the impulse flashover of air gaps corresponds in amount to the degree of departure from symmetry in the arrangement and shape of the electrodes. The flashover voltage is lowest when the positive polarity is applied to the electrode where the electric field is most intense and highest when the negative polarity is applied to that electrode.

The quantitative amount of the polarity effect on the impulse flashover of rod and plate electrodes in various arrangements is given in tables I and II and figures 5 and 6.

For the sphere-to-plate gap at spacings greater than 3 diameters the electric field becomes dissymmetrical to a degree which results in essentially the same negative and positive impulse flashover as for an equal spacing of the rod-to-plate gap.

2. The transition in the impulse voltage characteristics from a dissymmetrical to a symmetrical gap, whether the electric field is relatively uniform or not uniform, is rather abrupt particularly for the negative polarity. This transition is markedly evident for the

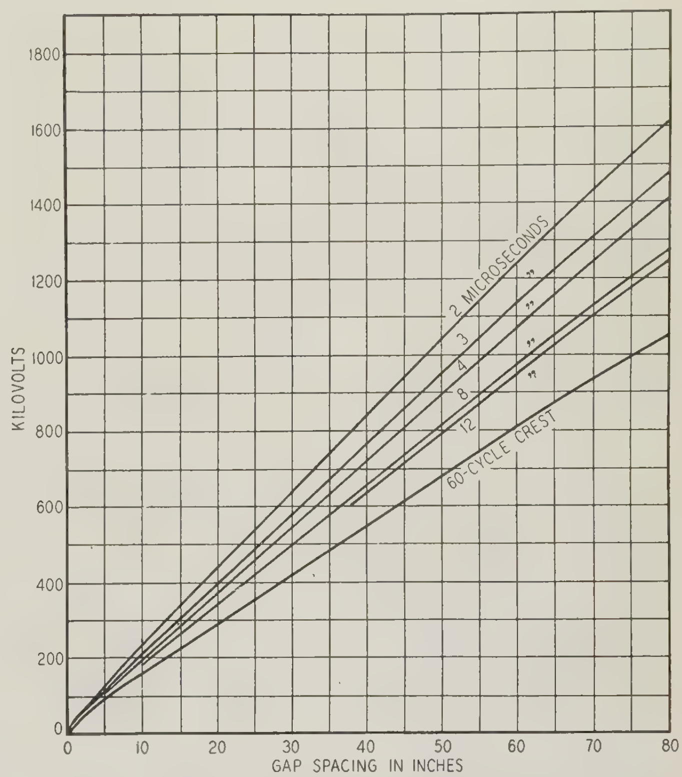



**Fig. 3. Positive impulse characteristics of rod gap**

Relative air density = 1.00; absolute humidity = 6.5 grains per cubic foot

sphere-to-plate gap as the spacing is increased above 2 diameters (figure 13) and also for the rod-to-plate-with-rod-extension gap (figures 5 and 6).

3. In contrast with the polarity effect where the negative impulse flashover exceeds the positive flashover as is the case for dissymetrical gaps with the field concentrated at one electrode, the negative impulse flashover for relatively uniform fields is less than the positive flashover voltage. This effect is revealed in the case of the sphere-to-sphere gap in figure 14, and also for the sphere-to-plate gap in figure 13 in which case the positive and negative curves actually cross at $^3/_4$ diameter spacing where the dissymmetry becomes sufficiently pronounced.

4. For the electrode shapes and arrangements having substantial dissymmetry, as stated in conclusion 1, the 60 cycle flashover voltage is less by a relatively small amount than the positive impulse minimum flashover voltage. This indicates, as confirmed also by other observations and tests, that 60 cycle flashover occurs on the positive polarity of the wave.

For the electrode arrangement where the electric field departs only slightly from uniform, as stated in conclusion 3, the 60 cycle and negative impulse flashover voltage are practically identical.

5. The presence of corona and streamer formation which precedes breakdown with the electrode shapes and arrangements having substantial dissymmetry also tends to modify and alter the effective physical electrode shape, particularly at 60 cycles, in which case corona persists diffusely for a considerable time before actual

sparkover occurs. The effects associated with corona and streamers are complex and introduce complicating factors in the phenomena of breakdown. An example of this corona effect is found in figures 9 and 10 where, at the wider spacings the flashover for the rod-to-plate gap is greater than that of the sphere-to-plate gap.

6. The 60 cycle flashover voltage of a sphere-to-plate gap bears a definite relationship to the rod-to-plate flashover voltage which for practical purposes may be expressed quantitatively. Thus from table III, the ratio of the flashover voltages for the 2 types of gaps at a given spacing expressed in sphere diameters is practically a constant for the various sizes of spheres and therefore may be plotted as a single characteristic curve.

## Rod and Plate Electrodes

### Description of Test, Technique of Measurement, Correction Factors

The electrode arrangement for the rod-to-plate gap is illustrated in figure 1. It consists of a 0.5-inch square cut, square rod suspended vertically above the center part of a horizontal 0.25 inch thick, 120 by 170 inch steel plate lying flat on the ground. A clearance from the gap to adjacent objects of not less than 4 times the largest gap opening was maintained. Observance of actual breakdown, both with 60 cycle and impulse voltages, indicated consistent flashover from the rod to the center of the plate, thus confirming that a condition of a true rod-to-plate gap existed. This fact was strikingly shown as any material reduction in the plate dimensions for the wider gap openings would be evidenced by a flashover between the rod to a corner of the plate, particularly with negative impulses.

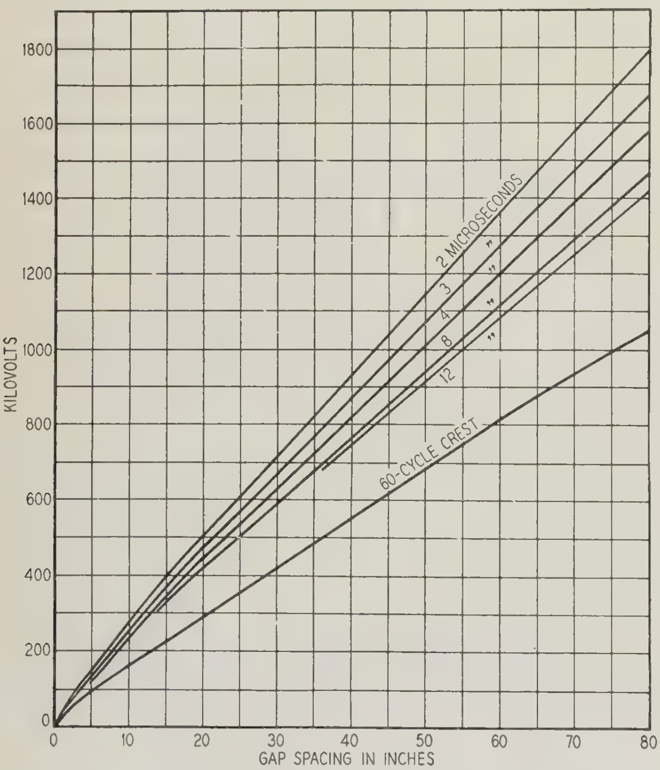



**Fig. 4. Negative impulse characteristics of rod gap**

Relative air density = 1.00; absolute humidity = 6.5 grains per cubic foot

The rod-to-plate gap with rod extension above the plate was exactly the same as illustrated in figure 1 except that in addition a segment of the rod of the desired length was set at the center of the plate extending vertically toward the suspended rod. The rod gap was mounted horizontally and conformed closely in its arrangement to the prescribed requirements for the coördination gap.[9,10] A clearance of more than 4 times the largest gap length was maintained from these gaps to surrounding objects. The 3 gap arrangements are shown in figure 5.

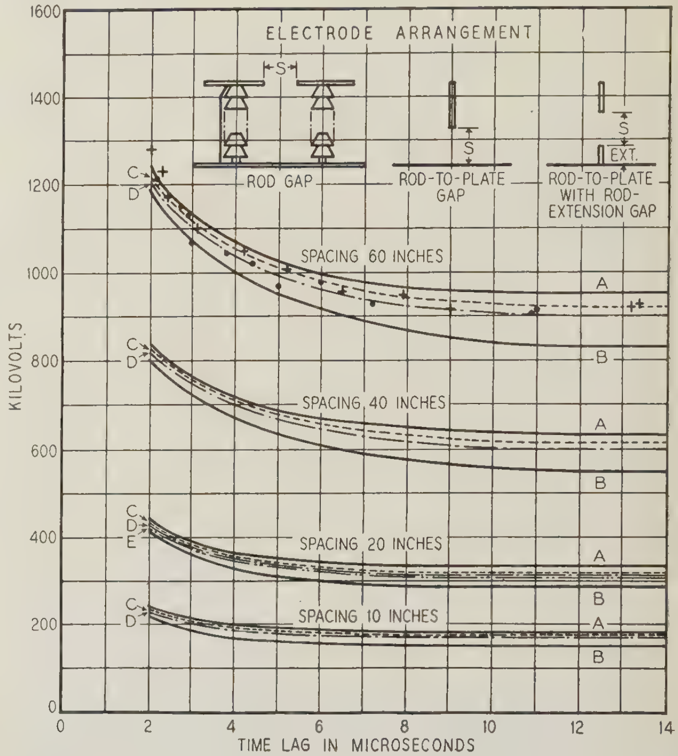



**Fig. 5. Comparison of positive voltage time-lag curves for rod, rod-to-plate, and rod-to-plate-with-rod-extension gaps**

Relative air density = 1.00; absolute humidity = 6.5 grains per cubic foot

A. Rod gap
B. Rod-to-plate gap
C. Rod-to-plate-with-rod-extension gap; ext. = 40% S
D. Rod-to-plate-with-rod-extension gap; ext. = 20% S
E. Rod-to-plate-with-rod-extension gap; ext. = 10% S

The impulse tests were made with a standard 1.5-40 microsecond wave. The data were analyzed according to the established methods, the voltage being measured at the crest and the time lag scaled on the oscillogram from the point on the front of the wave corresponding to the 60 cycle flashover voltage to the point of flashover on the tail. The test data were obtained under atmospheric conditions which departed usually less than 3 per cent from unity relative air density (25 degrees centigrade and 760 millimeters mercury) and varied from standard humidity (6.5 grains per cubic foot) on the average less than 3 grains. In order to compare all the data for one

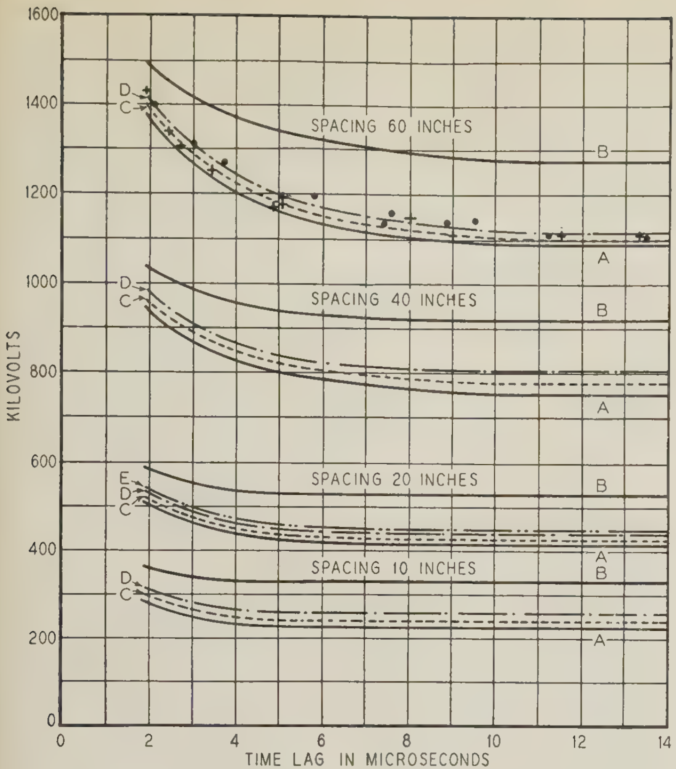



**Fig. 6. Comparison of negative voltage time-lag curves for rod, rod-to-plate, and rod-to-plate-with-rod-extension gaps. (See figure 5 for gap arrangement)**

Relative air density = 1.00; absolute humidity = 6.5 grains per cubic foot

A. Rod gap
B. Rod-to-plate gap
C. Rod-to-plate-with-rod-extension gap; ext. = 40% S
D. Rod-to-plate-with-rod-extension gap; ext. = 20% S
E. Rod-to-plate-with-rod-extension gap; ext. = 10% S

electrode arrangement on a common basis of unity air density and standard humidity, corrections were applied. For air density a correction inversely proportional to the relative air density was applied. The correction used for humidity for the various time lags was in accordance with the most recent data.[8–9]

The 60 cycle tests were made with a 1,000-kv 500-kva testing transformer having for engineering purposes a good sinusoidal wave form. The 60 cycle voltage was measured with the sphere spark gap as a reference standard using the most recent calibration.[5] The humidity correction factor applied for the 60 cycle voltage was 3 per cent per grain per cubic foot. This is the best correction factor now available based upon past tests, though observations of the experimental data obtained in the tests reported here indicate the possibility of further refinements in the correction factor applicable for the various electrode arrangements.

In general the air density and humidity correction factors applied to the experimental data counteract each other so that the effective correction is on the average 2 to 3 per cent and seldom more than 5 per cent. The interesting fact observed was that both the impulse and 60 cycle data, even when corrected by present methods to a common basis for comparison, could be reproduced on the average within 2 to 3 per cent and seldom would repeated check tests give curves departing as much as 5 per cent from previously established curves. Thus it is evident, though the corrections applied for atmospheric conditions may not be perfect, that the data presented here can be reproduced with sufficiently good engineering accuracy. As a matter of fact, however, more difficulty was experienced in checking 60 cycle data than for the case of impulse data, probably due to the correction factors.

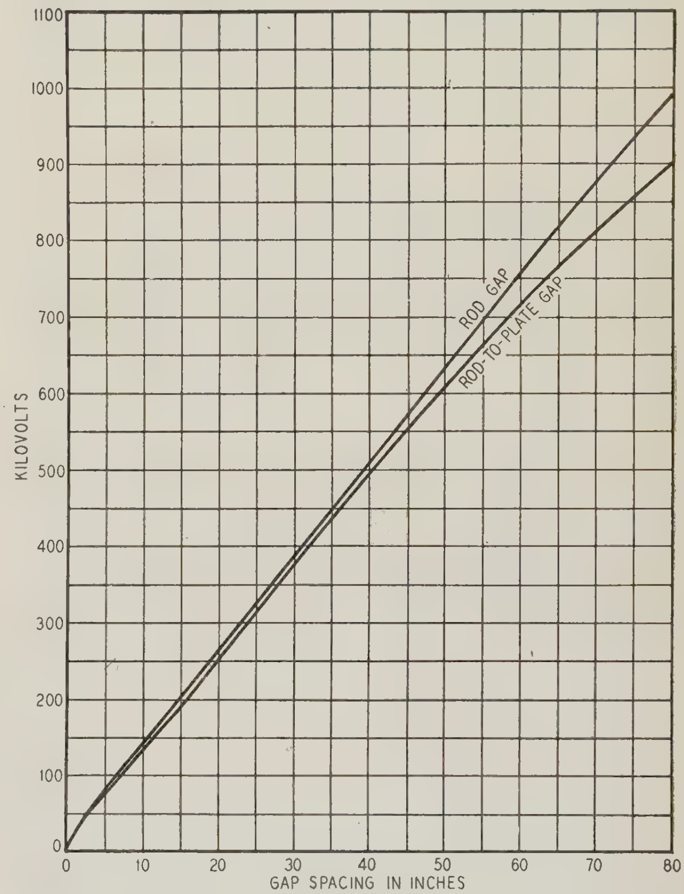



**Fig. 7. Sixty cycle flashover voltage for rod and rod-to-plate gaps**

Relative air density = 1.00; absolute humidity for rod gap curve = 3.0 to 3.7 grains per cubic foot and for rod-to-plate gap curve = 4.3 to 4.4 grains per cubic foot

**Table I—Comparison of Positive and Negative Impulse Flashover Voltage for Rod-to-Plate Gaps**

| Gap Spacing Inches | Ratio of Negative to Positive Flashover Voltages for Various Time Lags | | | | |
|---|---|---|---|---|---|
| | 2 μsec | 3 μsec | 4 μsec | 8 μsec | Full Wave* |
| 10 | 1.67 | 1.79 | 1.90 | | 2.18 |
| 20 | 1.42 | 1.52 | 1.59 | | 1.86 |
| 40 | 1.29 | 1.37 | 1.44 | 1.58 | 1.68 |
| 60 | 1.25 | 1.32 | 1.38 | 1.49 | 1.54 |
| 80 | 1.25 | 1.32 | 1.35 | 1.44 | 1.48 |

* The voltage corresponding to full wave is only slightly less than that for the longest time lag as shown in the curves.

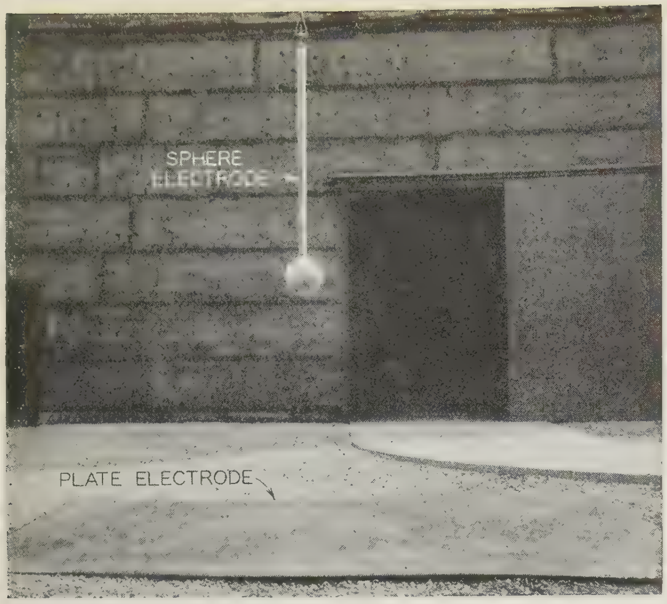



**Fig. 8. Sphere-to-plate gap**

Standard 25 centimeter sphere; 0.25 × 120 × 170 inch plate

## Rod-to-Plate Gap

The impulse data of this gap for spacings up to 80 inches are given in figure 2. The important impulse characteristic indicated by the data is the polarity effect. The negative curves particularly for the longer time lags are materially above the positive curves. Longer time lags are observed with the positive wave than with the negative. The 60 cycle curve is only slightly below the 12 microsecond time lag or full wave positive curve; this relationship thus indicates that the 60 cycle flashover occurs on the positive polarity. The marked polarity effects for this electrode arrangement are indicated in table I, where the flashover voltages at different time lags for the positive and negative waves are compared with each other.

## Rod Gap

The rod or coördination gap plays an important rôle in impulse testing and as a protective device. The data given in the curves of figures 3 and 4 represent respectively the positive and negative characteristics of the rod gap. Since the rod gap approaches a symmetrical arrangement it, therefore, is not affected by polarity effects as much as the rod-to-plate gap. It is enlightening to compare the relative flashover voltages for the rod-to-plate and the rod gaps. This comparison is made in table II.

## Rod-to-Plate Gap With Rod Extension Above Plate

The data in table II thus infer that a transition region exists between the charactersitics of the rod-to-plate and of the rod electrode arrangements. A rod-to-plate gap with various degrees of rod extensions above the plate was accordingly investigated both with positive and negative waves. The curves are given in figures 5 and 6 and reveal very pertinent data on the transition from the rod-to-plate to the rod gap characteristics. The transition is more abrupt for the negative wave than for the positive. For both polarities a 20 per cent rod extension above the plate results in practically a complete transition

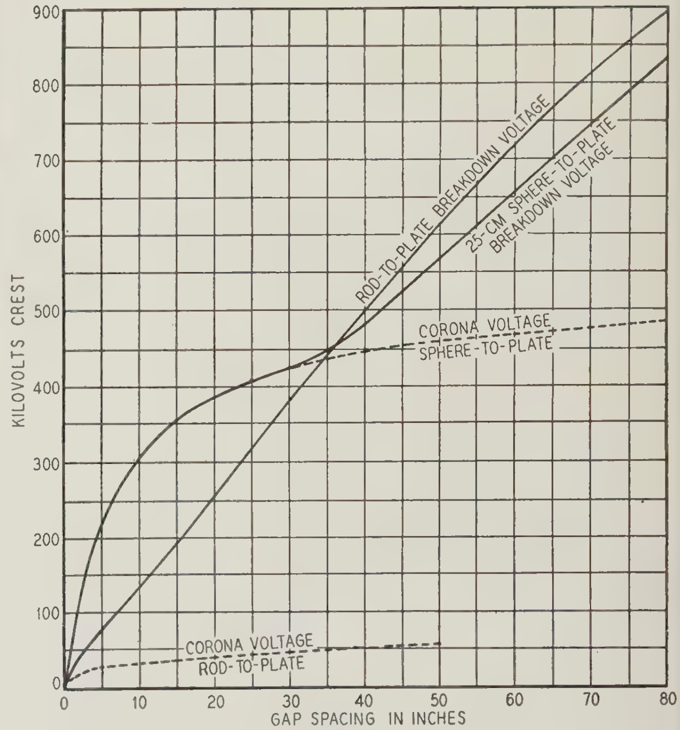



**Fig. 9. Sixty cycle flashover and corona voltages for 25 centimeter sphere-to-plate and rod-to-plate gaps**

Relative air density = 1.00; absolute humidity for sphere-to-plate gap data = 2.5 grains per cubic foot and for rod-to-plate gap data = 4.3 to 4.4 grains per cubic foot

from rod-to-plate to rod gap characteristics. The curves plotted in figures 5 and 6 for various amounts of extension are average data. The actual points, as illustrated for a few of the curves, are quite scattered and indicate a rather erratic performance in the transition from one gap to the other. For either the rod gap or the rod-to-plate gap the actual points (not shown) depart only a few per cent and seldom more than 5 per cent from the average curves indicated. The observations of flashover during the test are of practical interest as these have a bearing on the interpretation of the actual data. In the case of the positive wave a small rod extension above the plate resulted in a flashover from the suspended rod partly to the rod extension and partly to the plate, whereas for the negative wave, flashover occurred consistently between the suspended rod and the rod extension above the plate.

With 60 cycle voltage there is no great difference in flashover voltage between the rod and the rod-to-plate gaps; this can be seen from figure 7. In both cases breakdown is preceded by diffuse corona

discharge as is expected due to the low corona level of both gaps. The small departure of each curve from the corresponding positive impulse flashover for long time lag indicates 60 cycle flashover is associated with positive polarity. Due to the small difference between the 2 curves it was rather difficult to establish clearly the transition at 60 cycle voltage from the rod-to-plate to the rod gap. At 80 inch spacing, however, where the difference between the 2 curves is appreciable, the tests show that for various extensions above the plate there is a consistent and uniform transition from the curve of one gap to the other. At this spacing, the flashover voltage of the rod gap is 10 per cent above that of the rod-to-plate gap. A 10 per cent extension of the rod

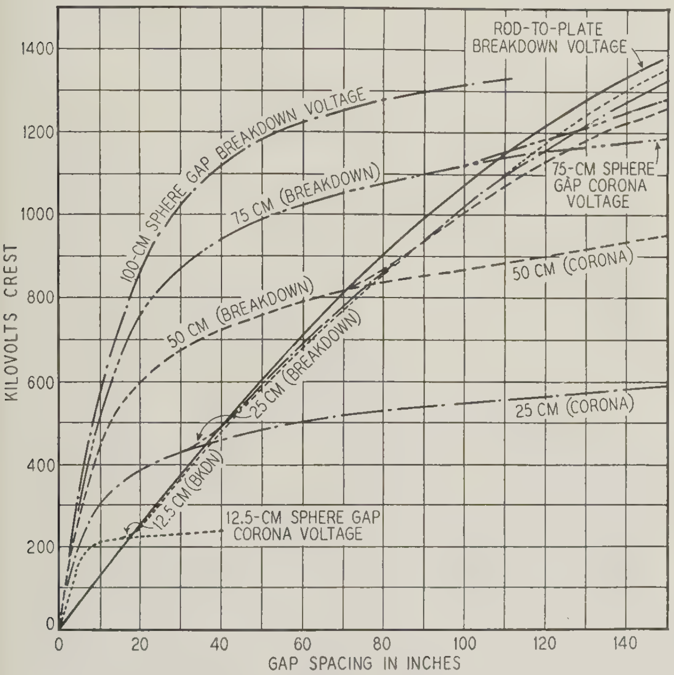



**Fig. 10. Sixty cycle flashover and corona voltages for 12.5, 25, 50, 75, and 100 centimeter sphere-to-plate gaps and flashover voltage for rod-to-plate gap**

For source of data see reference 17 at end of paper

above the plate increases the flashover, above that of the rod-to-plate gap, 3 per cent; a 20 per cent extension increases the flashover 5 per cent; and a 40 per cent extension, 7.5 per cent.

## Sphere and Plate Electrodes

### Description of Test, Technique of Measurement, Correction Factors

The electrode arrangement for the sphere-to-plate gap is illustrated in figure 8. The sphere electrode consists of a 25 centimeter standard sphere attached to a vertical, 2 inch rod, and the plate electrode is the same as described in connection with figure 1. The same measures were taken as in all previous tests to keep surrounding objects well removed from the gap. It was observed that even at the widest gap opening, flashover occurred consistently from the sphere to the center of the plate.

Data was obtained following exactly the same technique of testing and measurement as described previously for rod and plate electrodes.

For the sphere-to-plate electrodes the data are corrected to the common basis of unity relative air density; i. e., the correction factor applied is inversely proportional to the relative air density. It was deemed best not to apply any correction for humidity but rather to give the actual absolute humidity for

**Table II—Comparison of Impulse Flashover Voltages for Rod-to-Plate and Rod Gaps**

| Gap Spacing Inches | Flashover Strength in Per Cent of Positive Rod-Gap Flashover | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Positive Polarity | | | | Negative Polarity | | | |
| | Rod Gap | | Rod-to-Plate Gap | | Rod Gap | | Rod-to-Plate Gap | |
| | 2 μSec | Full Wave* | 2 μSec | Full Wave* | 2 μSec | Full Wave* | 2 μSec | Full Wave* |
| 10 | 100 | 100 | 91 | 83 | 117 | 127 | 150 | 178 |
| 20 | 100 | 100 | 94 | 84 | 114 | 124 | 132 | 156 |
| 40 | 100 | 100 | 95 | 86 | 111 | 117 | 124 | 144 |
| 60 | 100 | 100 | 95 | 87 | 110 | 114 | 120 | 134 |
| 80 | 100 | 100 | 97 | 88 | 111 | 114 | 121 | 131 |
| Average | 100 | 100 | 94 | 86 | 113 | 119 | 129 | 149 |

*The voltage corresponding to full wave is only slightly less than that for the longest time lag as shown in curves.

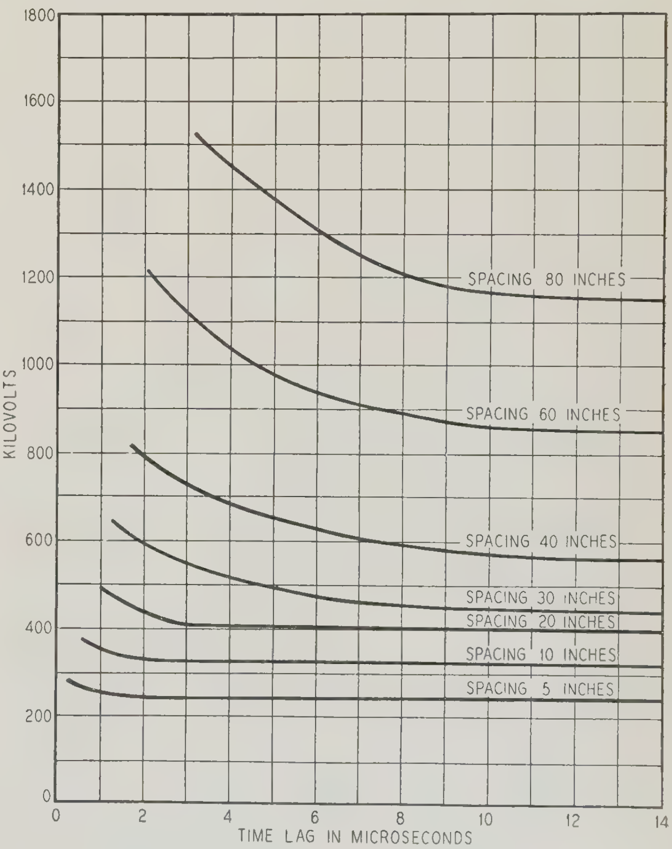



**Fig. 11. Positive voltage time-lag curves for 25 centimeter sphere-to-plate gap**

Relative air density = 1.00; absolute humidity in grains per cubic foot as follows: 80 inch spacing, 8.3; 60 inch, 8.1; 40 inch, 7.1; 30 inch, 7.1; 20 inch, 6.3; 10 inch, 4.2; 5 inch, 4.4

the data. The atmospheric conditions departed, however, only slightly from standard: the air density was not greater than 2 per cent and the humidity was seldom more than 2 grains per cubic foot from standard. Previous investigations on the sphere spark gap[5–7] have shown that for relatively short gap spacings humidity has no effect on sparkover; it is only therefore for the wide spacings, where breakdown is preceded by streamer formation or corona, that humidity would be expected to have any effect on the flashover of the sphere-to-plate gap.

**Table III—Comparison of 60 Cycle Flashover Voltage of Sphere-to-Plate and Rod-to-Plate Gaps**

| Spacing in Sphere Diameters | Ratio of Sphere-to-Plate Flashover Voltage to Rod-to-Plate Flashover Voltage for Equal Spacings | | | | |
|---|---|---|---|---|---|
| | 12.5 cm Sphere | 25 cm Sphere | 50 cm Sphere | 75 cm Sphere | 100 cm Sphere |
| 0.5 | | 310 | 344 | 340 | 340 |
| 1 | 250 | 242 | 240 | 231 | 230 |
| 2 | 170 | 150 | 147 | 144 | 142 |
| 3 | 116 | 113 | 110 | 111 | 110 |
| 3.5 | 102 | 102 | 101 | 103 | 102 |
| 4 | 97 | 96 | 97 | 98 | |
| 5 | 97 | 94 | 94 | 93 | |
| 7.5 | 97 | 94 | 94 | | |
| 10 | 97 | 95 | | | |
| 15 | 96 | 96 | | | |
| 20 | 95 | | | | |
| 30 | 98 | | | | |

## Sphere-to-Plate Gap

The 60 cycle flashover voltage of the 25 centimeter sphere-to-plate gap is given in figure 9; the flashover voltage of the rod-to-plate gap is given also for comparison. Similar data by Goodlet, Edwards, and Perry,[17] are in such good agreement with those in figure 9 that their data for various sizes of spheres to plate and for the rod to plate are reproduced in figure 10. The data for the sphere-to-plate flashover are compared to the rod-to-plate flashover in table III. The comparison reveals an interesting relationship characteristic of the sphere-to-plate gap. It is significant to note that at a gap spacing close to 3.6 sphere diameters the flashover curve for the sphere-to-plate gap intersects the rod-to-plate curve. For shorter spacings the sphere-to-plate gap flashes over at a higher voltage and for larger spacings at a lower voltage than the rod-to-plate gap by an amount given in table III.

The 60 cycle corona levels for the sphere-to-plate and rod-to-plate gaps are given in figures 9 and 10. These levels have a bearing on the flashover curves and the nature of the breakdown. During the tests it was observed for the sphere-to-plate gap that as the opening exceeds 3.6 sphere diameters "corona" appears abruptly in the form of streamers. These streamers extend out 2 inches and more at the instant they first appear and increase in length as the gap spacing is further increased above the critical value. This sudden streamer formation on the sphere-to-plate gap is rather contrasting when compared to the corona glow gradually increasing into diffuse corona and streamers which precede flashover of the rod-to-plate electrode.

The impulse characteristics of the sphere-to-plate gap are given in figures 11 and 12. Each curve is based upon 10 or more actual points which deviate individually less than 2 per cent in general from the average curve drawn; only a few points in all the experimental data depart as much as 5 per cent. It should be noted that for spacings up to one sphere diameter the voltage-time lag curves are flat down to 1 or 2 microseconds; thus, these curves are similar to corresponding curves for the sphere-to-sphere gap.[7] For the larger gap spacings the curves assume more and more the same form as for the rod-to-plate gap. Another pertinent characteristic is that the voltage-time lag curves for the negative waves are substantially flat compared to curves for positive waves. The negative values exceed the

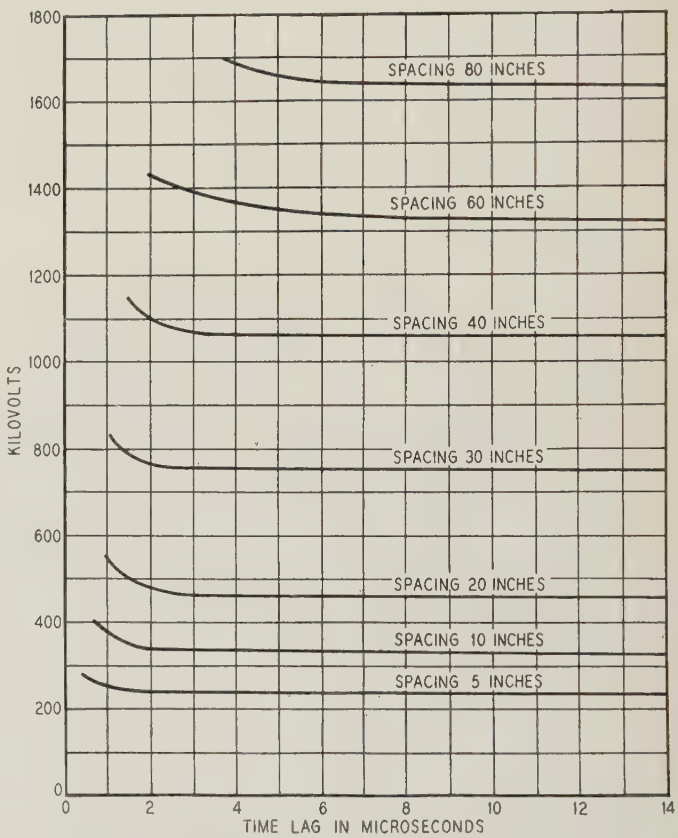



**Fig. 12. Negative voltage time-lag curves for 25 centimeter sphere-to-plate gap**

Relative air density = 1.00; absolute humidity in grains per cubic foot as follows: 80 inch spacing, 7.9; 60 inch, 7.4; 40 inch, 6.8; 30 inch, 6.6; 20 inch, 6.5; 10 inch, 3.1; 5 inch, 3.4

positive for spacings greater than one diameter over the range of time lags investigated.

A comparison of the 60 cycle and the full wave impulse flashover curves for the sphere-to-plate gap is shown in figure 13. For spacings $^3/_4$ diameter and less the positive impulse curves are above the negative, whereas the negative and 60 cycle are practically identical, thus indicating a similar character-

istic as for the sphere-to-sphere gap,[5–7] an example of which is shown in figure 14. The negative and positive curves cross each other at a spacing about $^3/_4$ sphere diameter and beyond this the negative curve exceeds the positive a greater and greater amount with wider gap spacings. The polarity effects become strikingly evident between 2 to 3 sphere diameter spacings, yet in this transition region the data could be reproduced and checked within an accuracy of 2 per cent from the average.

It was indicated in conjunction with figure 9 that above 3 diameter spacings the 60 cycle flashover curve for the sphere-to-plate gap is nearly the same as the rod-to-plate curve. This characteristic is again revealed in figure 13 where beyond the transition region near 3 diameters the positive and negative impulse curves are practically identical with the corresponding curves for the rod-to-plate gap in figure 2. Furthermore, the 60 cycle curve in figure 13 is relatively close to the positive impulse curve as compared to the negative. All these observations thus show in a simple and general way the similarity of the characteristics of the sphere-to-plate gap as compared to the rod-to-plate gap.

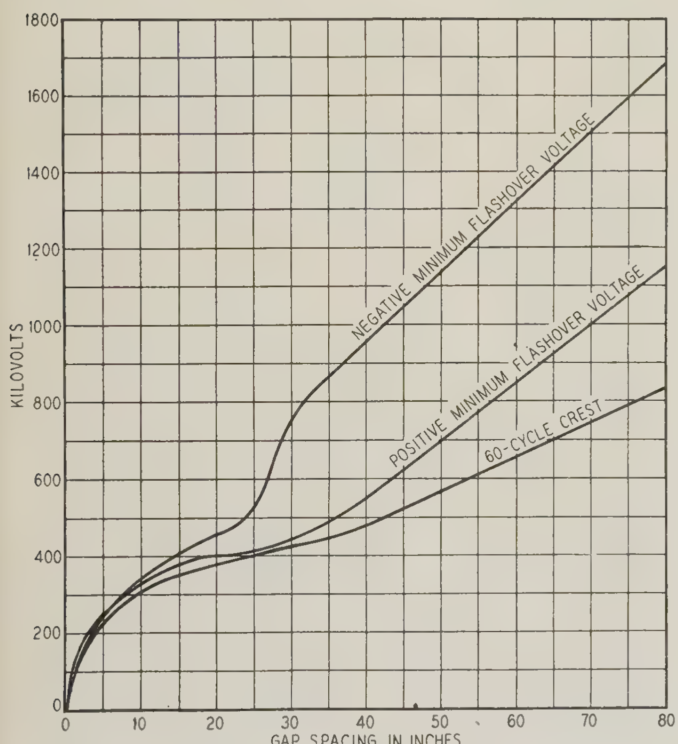



**Fig. 13. Positive and negative impulse, and 60 cycle flashover voltage for 25 centimeter sphere-to-plate gap**

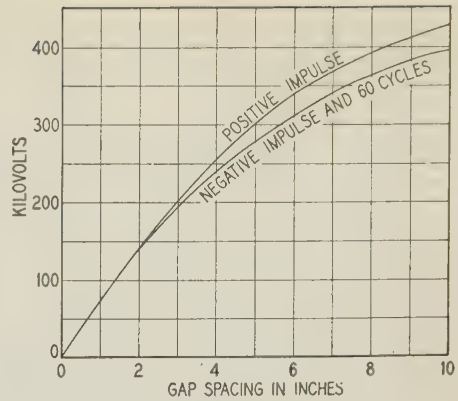
Relative air density = 1.00; absolute humidity as per figures 9, 11, and 12

Sphere-to-Sphere Gap

This type of gap is particularly important as a reference standard for voltage measurement where its use is limited to spacings below one diameter. Comprehensive investigations of its 60 cycle and impulse characteristics have been published during the past year.[5–7] The impulse characteristics of the sphere spark gap to very short impulse waves are given in a recent publication.[7] Figure 14 gives the impulse and 60 cycle flashover voltage of the 25 centimeter sphere gap up to one diameter spacing; these curves are typical of the characteristics of sphere gaps of other sizes.

**Fig. 14. Positive and negative impulse, and 60 cycle flashover voltage for 25 centimeter sphere-to-sphere standard spark gap**

Relative air density = 1.00

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# Discussions

## Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON THIS and the following 15 pages appear all remaining unpublished discussions of papers presented at the 1934 A.I.E.E. summer convention, Hot Springs, Va., June 25–29, as follows: (1) all papers except one presented at the session on power generation (complete discussion on one paper was published in the November issue); and (2) all papers presented at the session on instruments and measurements. All discussions of the foregoing papers received in complete and acceptable form at Institute headquarters, and subsequently reviewed and recommended for publication by A.I.E.E. technical committees, are included. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

## A 7,000-Ampere Station Bus

**Discussion and authors' closure of a paper by H. L. Unland, W. B. Morton, and V. R. Bacon published in the June 1934 issue, and presented for oral discussion at the power generation session of the summer convention, Hot Springs, Va., June 29, 1934.**

**F. R. Dallye:** The authors of the paper which has just been presented are to be commended for presenting data in practical form on a subject as timely as this one. Channel conductors for heavy currents were introduced by the Aluminum Company of America in 1929 after the erection of a complete blooming and structural mill for rolling strong alloy structural shapes. This permitted the fabrication of high purity aluminum channels in lengths up to 90 ft. The first large installation of these channel conductors was in the company's own plate mill at Alcoa, Tenn., where 2 parallel 3-phase circuits, 1,600 ft long, distribute 440-volt power to various mill motor, electric furnace, and lighting loads.

In the development of this new use for structural channels a variety of current rating tests were conducted on several sizes. These were carried out in a complete enclosure 35 ft long, having a cross section of about 6 by 7 ft, to accommodate the 30-ft length of conductors under test. This allowed circulation of air around the buses but prevented drafts.

One important finding is believed to be of general interest, namely, that the amount of space between the flanges of 2 channels forming a phase conductor materially affects the current rating. One experiment employed 8-in. channels having a web thickness of 0.395 in. and a total cross sectional area of 9.56 sq. in. for the 2 channels. It was found that with the flanges butted together, in effect forming a rectangular tube, 3,800 amp caused an average temperature rise of 30 deg C. With a 1/4-in. space between flanges the current was increased 15 per cent, and with a 3/4-in. space 30 per cent for the same temperature rise. When channels of this size are assembled in the usual square formation this space between flanges is 3 1/8 in. and the corresponding current for 30 deg rise is 5,800 or an increase of over 50 per cent.

A striking example showing the advantageous distribution of metal in structural channel sections was demonstrated when 3 1/2-in. extra heavy IPS (iron pipe standard) aluminum tubular bus was tested along with a conductor made up of 2 4-in. channels having 0.247 inch web thickness. It will be noted that the width and height of both of these conductors is 4 in. and that their cross sectional areas are exactly the same, 3.68 sq in. A current of 2,000 amp produced a temperature rise of 30 deg C in the tube, which was new and bright. The channels carried 2,960 amp with the same temperature rise. The finish of new rolled channels is not quite as bright as the new tubing, but even well weathered tubing of this size has a rating of only 2,300 amperes in comparison.

**H. B. Dwight:** The tests made on practical busbars at currents up to 7,000 amp will undoubtedly prove very useful in the design of this type of apparatus. The tests made with 3-phase current of this large amperage are noteworthy.

The shifting of the hottest spot by reversal of the phase rotation, shown in Fig. 3 of the paper, evidently corresponds to the similar behavior of the heating of the sheaths of single-conductor cables with flat spacing, for which a calculation was given by eq 22 in my paper, "Proximity Effect in Cable Sheaths," A.I.E.E. TRANS., September 1931, p. 997. The phenomenon can be illustrated by simple wire circuits shown in Fig. 1 of this discussion.

Let there be 9 long parallel wires as in the figure, the lower pairs forming short-circuited loops. Let $R$ be the resistance per cm in absolute units, and $r$ the radius of the wires in the loops, and let the power currents be

$$I_A = (-0.5 + j\,0.866)I$$
$$I_B = I$$
$$I_C = (-0.5 - j\,0.866)I$$

Taking voltages in the first loop and dividing by $j\,\omega$,

$$I_A \log_n \frac{b^2}{a^2} + I_B \log_n \frac{s^2 + b^2}{s^2 + a^2} + I_C \log_n \frac{4s^2 + b^2}{4s^2 + a^2} + 2I_1\left(\frac{R}{j\omega} + \log_n \frac{c^2}{r^2}\right) + 2I_2 \log_n \frac{s^2 + c^2}{s^2} + 2I_3 \log_n \frac{4s^2 + c^2}{4s^2} = 0 \quad (1)$$

where $\log_n$ denotes natural logarithm. This and 2 equations for the other loops give the 3 loop currents in terms of the amperage, $I$, of the power current.

Putting $a = 8$ in., $b = 12$ in., $c = 4$ in., $r = 0.5$ in., $s = 5$ in., frequency = 60 cycles, and conductivity = 20 per cent of that of copper at 20 deg C, the following are obtained:

$$(0.0372 + j\,0.358)I + (8.32 - j\,9.02)I_1 + 0.989\,I_2 + 0.297\,I_3 = 0 \quad (2)$$

$$0.1697\,I + 0.989\,I_1 + (8.32 - j\,9.02)I_2 + 0.989\,I_3 = 0 \quad (3)$$

$$(0.0372 - j\,0.358)I + 0.297\,I_1 + 0.989\,I_2 + (8.32 - j\,9.02)I_3 = 0 \quad (4)$$

Then $|I_1| = 0.0289\,I$, $|I_2| = 0.0141\,I$, and $|I_3| = 0.0306\,I$.

The right hand loop has 6 per cent more current, and 12 per cent more heating, than the left hand loop. If the phase rotation were reversed, the left hand loop would have the larger current.

If a round tube is bent into a square shape, the a-c resistance is increased because, in addition to the crowding of the current toward the outer surface, the current also crowds to some extent toward the corners.

In Fig. 5 of the paper it is shown that the heating of a steel member depends on its resistance and its heat dissipating surface, as well as on its size and its nearness to the current. The value of practical tests is obvious.

The indirect method of measuring the a-c resistance of the large conductors, as described in the paper, is interesting and accurate. The writer has used an alternative

method of obtaining this result. See the test curves of skin-effect resistance ratio in Figs. 4 and 5 in "A-C Conductivity of Iron Pipe," *Electric Journal*, June 1926, p. 297. A curve of watts loss against temperature rise was first determined by direct current, and then the watts loss with alternating current at a certain temperature rise was taken to be the same as the

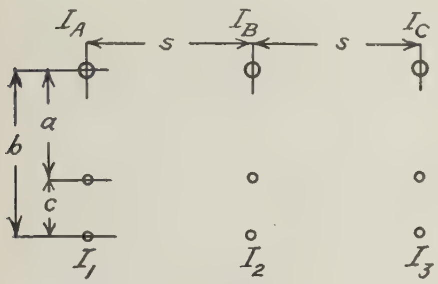



**Fig. 1. Arrangement of wires**

watts loss with direct current at the same temperature rise.

It may be of interest to state that the curve of temperature rise by free convection for a stationary body, plotted on watts loss as a base, is a curve which bends slightly to the right, as in Figs. 1 and 2 of the article on iron pipe previously mentioned, or as shown by tests on copper conductors. As the temperature increases, the flow of air becomes faster and the watts dissipated become greater in proportion.

**H. C. Forbes:** Regarding the determination of the a-c resistance of buses, the authors state that "to measure directly the a-c resistance of large conductors of irregular section considerable difficulty and expense would be encountered and even then the accuracy would be subject to question." I agree with that statement, and I would like to call attention to the fact that an indirect method of determining the a-c resistance of rectangular conductors which was described by L. J. Gorman and myself in a paper entitled "Skin Effect in Rectangular Conductors" (A.I.E.E. Trans., June 1933, p. 516) is well suited to the determination of the a-c resistance of conductors such as the authors describe. This method consists of making tests at high frequency on miniature conductors having dimensions proportional to those of the conductor for which the information is desired.

Details of this method are given in the paper to which I have referred. Its application requires some rather special equipment which it is hardly worth while to set up where an investigation of only one conductor is desired. In order to overcome this difficulty I am hopeful that some of our electrical manufacturers or perhaps our universities may see fit to install a permanent outfit in their laboratories so that they would be able to determine the skin effect of any conductor of irregular cross section by making a measurement on a miniature model. I believe that if such a service were available it would be patronized rather extensively by the electrical industry and I make the comment at this time with the thought that it may help to arouse an interest in the matter.

## Discussions—Publication and Correlation

Among the several important features of the unified publication plan put into operation by the Institute beginning with the January 1934 issue of Electrical Engineering were improvements in the method of handling discussions. Among the desired improvements were: (1) reduction in the time delay prevailing between presentation and publication; (2) making discussions accepted for publication available to the entire membership of the Institute; (3) convenient and thorough indexing, and effective correlation.

**Prompt Publication.** The bulk of the discussion presented at the 1934 winter convention was published in the March and April issues of Electrical Engineering and, under normal circumstances, would have been completed in the May and June issues. However, the development of the 50th anniversary issue in May, together with the necessity for advance publication of technical papers on the programs of the summer and Pacific Coast conventions, required that the publication of further discussion be suspended until September. Recovery from that situation has been steady, however, if slow. With this December issue, the publication of summer convention discussion including closures is completed; discussions and closures from the Pacific Coast convention are scheduled for the January and February 1935 issues. Thus the schedules will be cleared, so that the publication of discussion from the forthcoming winter convention can, with the coöperation of discussors and reviewers, be begun in the March issue and continued on a regular and further improved program.

**Complete Circulation.** Beginning with its publication in Electrical Engineering, under the unified publication plan, discussion was made available to the entire membership, thereby effectively rounding out the Institute's publication service, and making generally available a greatly increased quantity of important and timely information.

**Annual Index.** References to discussions will constitute an important part of the hundreds of entries that will appear in the 1934 Annual Reference Index. Particular care has been exercised to carry out a comprehensive system of multiple entries embracing all discussions published during the year. A reference to all discussion (if any) of a paper will be given in this index under *each* of the several (average 5) entries of the subject and title of *each* paper.

**The 1934 Annual Reference Index will be issued in January 1935 and mailed without charge to all members or subscribers who request it.**

**W. M. Hanna:** Although the authors made their study to obtain an answer to a specific problem, the test data which they have obtained forms a considerable addition of useful information on heating of magnetic members. The results of the experiments on short-circuiting strips and grids are especially interesting and are of probably the most direct and immediate value to the industry.

The heating of the bus itself has been only touched on, and properly so because it was soon found out that the one consideration of importance was forced convection. It would be interesting to know what air velocities are found necessary to keep the bus cool, and what effect this air has on the temperature of the nearby structural members.

In Figs. 5 and 10 is shown an apparent inconsistency in that the 10-in. beam ran hottest, the 24-in. beam next, and the 20-in. beam coolest. Heating should be directly proportional to some function of the beam dimension parallel to the conductor, and should be inversely proportional to functions of the cross section area and periphery. The principal flux concentration is in the surface next to the conductor. A large cross section provides better heat transfer away from the hot spot and a large periphery provides better heat dissipation. Examination shows that the 20-in. beam is larger in proportion to its depth than the 24-in. beam, and in consideration of the foregoing it is logical that it should be cooler.

Other factors affecting the heating besides dimensions are the permeability, resistivity and roughness of the magnetic material. The authors made comparative tests on silicon and carbon steel beams and found that the difference was negligible. It would be very interesting to see if the values of permeability and resistivity of the 2 beams were very nearly the same.

The variation of test points from the curves as plotted would indicate the effect of such variables as air movement, surface roughness, etc., and data concerning this variation would be very valuable to future investigators.

**L. J. Gorman:** This paper gives valuable information based on a comprehensive series of tests, particularly in reference to the induced current and consequent heating in metallic structures adjacent to buses carrying large currents. The data given in the paper are a valuable contribution to the knowledge on this subject. I have noted with particular interest the paragraph on skin effect and the test method of determining a-c resistance by means of heating and cooling curves.

In the calculation of a-c resistance, the authors assume that the ratio, thickness to diameter, for a cylindrical conductor could be replaced by the ratio of thickness to the side of the square in the case of the hollow square conductor. Based on the results of tests on solid conductors, published in a paper presented by H. C. Forbes and the writer at the January 1933 A.I.E.E. convention in New York City, it is believed that this assumption will give calculated values of a-c resistance that are from 5 to 10 per cent too low. The tests here referred to showed that the ratio of a-c to d-c

resistance in a solid square conductor is appreciably higher than in a solid round conductor having the same parameter. Although no experimental data were obtained on tubular or hollow square conductors, it is believed that the general relationship between solid, round, and square conductors would hold more or less in the case of tubular and hollow square conductors of the same parameter. In the square structure there seems to be a tendency for alternating current to crowd into the corners, thereby increasing the skin effect. It is believed, therefore, that the test values for a-c resistance given in the paper are more nearly in accordance with the facts than the calculated values would indicate.

Referring to items Nos. 3 and 4 in Table I giving the d-c resistance, and to the test a-c resistance values for the same test bars, it will be noted that the ratio of a-c to d-c resistance is 1.53 in the case of item No. 3 and 1.6 in the case of item No. 4. These ratios correspond very nearly to the a-c to d-c resistance ratios for solid strip conductor having a width and thickness ratio of 8 to 1 and corresponding parameters. This result seems to indicate good design in the hollow square conductors from the standpoint of skin effect and a-c resistance.

The tests reported by Mr. Forbes and the writer were made on miniature buses at high frequencies ranging from 22 to 287 kc. The test results agreed very closely with results obtained at lower frequencies and published by Messrs. Kennelly, Laws, and Pierce. It is believed that the high frequency method of test could be very readily applied to the type of bus discussed in the paper. The heating and cooling method mentioned by the authors is of particular interest in that it requires no special testing equipment.

**L. A. Kilgore:** The authors of this paper have made a very real contribution to the knowledge of losses and heating in structural steel and other metal parts near a high current bus. Their chief purpose was to solve a practical problem and they have done this very well by experimental set-ups in the laboratory and a check test on the actual structure.

It would seem at first glance that the problems presented here are too complicated for any quantitative theoretical analysis. However, by making use of certain principles which have been used with considerable success in the determination of losses due to stray fields in electrical machines, the writer was able to predict roughly the magnitude of loss and temperature and the behavior of copper bands and amortisseur grids.

Such a method of analysis if carried out very carefully and checked against the existing test data should be useful in extending the results to other special cases, and perhaps to develop some approximate formulas or curves to apply to general cases.

The principles referred to are the use of graphical flux mapping, as described by J. F. Calvert (*Electric Journal*, March to October 1928) and others, to determine the flux and current distribution; and the use of Rosenberg's formula or some of the other formulas for calculating the current and loss produced by the flux traveling in the surface of the adjacent iron parts.

The method of graphical flux mapping may also be used as shown in Fig. 2 of this discussion to determine the actual current distribution in a conductor of the type described.

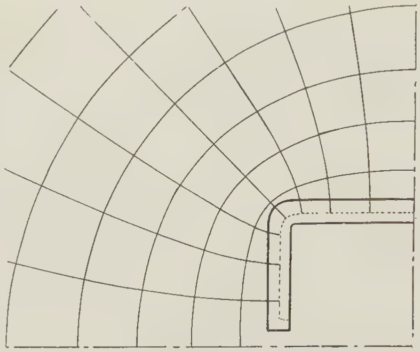


**Fig. 2. Flux plot for determining current distribution in 6-in. channel conductors**

The effective depth of penetration of the flux for 60-cycle flux in copper at 60 deg C as calculated by Steinmetz's formula is 0.256 and for the current the effective depth of penetration is 0.361. In plotting the field the assumption is made that no flux goes deeper than the effective depth of flux penetration shown by the dotted line in Fig. 2.

The loss is calculated for each element of current from the width of the element in the copper and the effective depth of current penetration. This gives a net ratio of a-c to d-c resistance at 60 cycles and 60 deg C of 1.56. The authors' test results indicate a ratio of 1.6. This method may also be applied where the conductors are sufficiently close to affect the current distribution in each other; about the only limitation is that the actual copper be thicker than the effective depth of penetration.

For the case of a single steel beam parallel to current carrying conductors the flux field is 2 dimensional and can be readily plotted for 2 special cases. Figure 3 was plotted on the assumption that the iron has infinite permeability and no damping. Figure 4 was plotted on the assumption that the iron is a perfect damper. These 2 fields permit calculation of the actual flux and loss in the beam. In Fig. 3 the total flux entering the beam is assumed to divide on the 2 sides of the beam in a certain ratio, and the ampere turns for each side calculated. If the ampere turns on each side are not equal, a new division is tried. The distribution of the currents induced in the beam will be approximately the same as that shown in Fig. 4. The ampere turns per inch ($H$) are calculated as:

$$H = \frac{f}{\rho B_s}\left(\frac{\phi \text{ in.}}{5640}\right)^2$$

where $f$ = frequency, $\rho$ = resistivity (ohms per in. cube), and $B_s$ = saturation density (use 120,000).

The current required to produce a certain flux as determined from Fig. 3 and the current required to balance the induced currents produced by the flux are determined from Fig. 4. These are added at 45 deg phase difference to give the total current in the conductor. This 45 deg phase displacement between flux and current was derived by Steinmetz and has been demonstrated by test.

The loss density $W$ in watts per sq in. may be calculated from the flux per inch ($\phi$ in.) traveling in the iron surface by Rosenberg's formula:

$$W = \frac{2.4}{\rho B_s}\left(\frac{}{60}\right)^2\left(\frac{\phi \text{ in.}}{10^4}\right)^3$$

In the case of the 24-in. beam, 17 in. from the conductor as shown in Fig. 11 of the paper, the average watts per sq in.

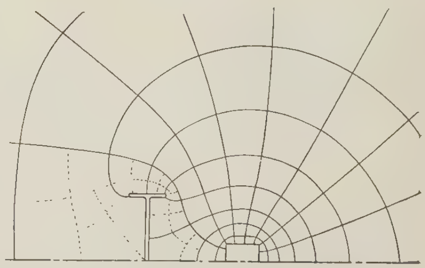


**Fig. 3. Flux entering a steel beam parallel to a single conductor, assuming infinite permeability and neglecting damping**

were calculated to be 0.27 and 0.15 at 7,000 and 5,000 amp, respectively. This loss density gives a calculated rise of 33 deg and 18.5 deg for the 2 cases, which checks the test value quite well.

The case of beams at right angles to the conductors is somewhat more difficult, since the field is not truly 2 dimensional

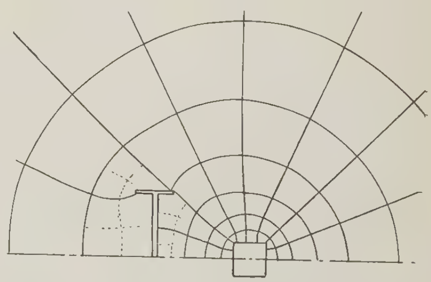


**Fig. 4. Flux plot for determining current required to balance induced currents plotted, assuming the steel to be a perfect damper**

and some approximate assumptions are necessary. For the case of the 3 phase conductors $5^1/_2$ in. from a 15-in. beam, as shown in Fig. 3 of the paper, the total flux entering the beam was determined by Fig. 5 of this discussion, using an average spacing equal to the distance to the center of the beam.

In order to simplify the flux plotting, the 3-phase current was resolved into 2 components: One flows in on phase $A$ and out on $C$ equal to 0.866 times the maximum phase current, and a second component (equal to the phase current) flowing in on phase $B$ with half returning in phases $A$ and $C$. These components are 90 deg in time phase. The flux fields assuming infinite permeability are shown for the 2 components on the left and right halves of Fig. 5.

Two flux plots assuming the iron to be a perfect damper were made and the current and loss calculated as before for each component separately. An accurate calculation of the exact loss distribution would require that the resultant current at each point be determined. The average power per unit cube for the 15-ft beam shown in Fig. 3 of the paper was calculated as 0.22 watts per sq in., which gives an average rise of 50 deg C for a beam covered with about 8 in. of concrete. The calculation of the maximum temperature involves the flow of heat along the beam as well as the actual distribution of loss; this is more difficult but not impossible.

The shift in the point of maximum temperature with the reversal of phase rotation as shown in Fig. 3 of the paper can be explained at least qualitatively as follows: If the 3-phase current is resolved into the 2 components of current mentioned above, these 2 components of current are 90 deg in time phase but the currents induced by them in the beam are not 90 deg apart. The first component flowing in the 2 outer conductors produces considerable demagnetizing ampere turns, so that the net current in the beam due to this component lags the total current by something less than 45 deg. The induced currents due to the second component are not very effective in limiting the flux entering the beam, hence the flux is nearly in phase and the induced current about 45 deg out of phase with the conductor current.

If the induced currents lagged the conductor currents by the same angle for each component, the loss distribution would be symmetrical about the center conductor. But with the difference in lag mentioned above, the induced currents due to the 2 components do not add at right angles, hence the resultant current on one side is higher. Since reversing the phase rotation is equivalent to reversing one component, it changes the side on which the resultant current is highest and so produces the observed shift in the maximum temperature.

The authors mention the possibility of currents induced in loops formed by conduit and show how it can be protected from a 3-phase bus by a copper grid. In stations

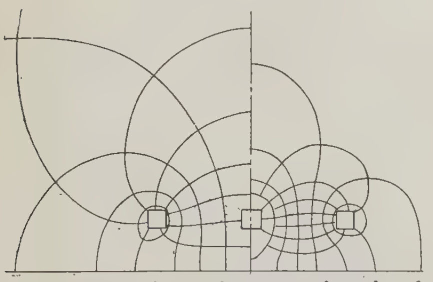


**Fig. 5. Plot of flux about a 3-phase bus for 2 components of the current**

where the phases are separated on different floors, the structural steel will form similar loops unless the joints are insulated. Calculations made using the principles outlined above show that in such a structure with a 5,000-amp bus about 900 amp flows in the adjacent beams with about 30 deg C rise. It is difficult to protect the beams against this circulating current unless they are insulated. An amortisseur grid to protect the beams would in this case have to carry nearly as much current as the main conductors.

**H. W. Papst:** The work of Messrs. Unland, Morton, and Bacon reveals the multitude of problems which are encountered in conductor design when the usual current capacities are exceeded. Either the problem of installing a 7,000-amp bus in the space allotted for one of 4,000-amp capacity or that of overcoming magnetic heating difficulties encountered when such highly inductive currents must pass near steel work represents one of large proportions. The fact that extensive investigations of this nature have been made before and yet very little of the information previously obtained was of assistance in solving the particular problems involved in this case, show the necessity that existed for more research work to establish quantitative relations between alternating currents, temperature rise of conductors, and induced heating in steel work.

It is of interest to note that the increase in capacity from an old 4,000-amp bus to a 7,000-amp bus was accomplished with an increase in copper from 27 lb, to only 51.2 lb per ft at the same time that external conditions became decidedly more unfavorable.

Ordinarily in new station design most of the magnetic problems encountered in this installation could be avoided. However, it is only through the experiences as described by the authors on such necessary modifications in existing plants that the necessary precautions can be foreseen and provided.

**O. R. Schurig:** The authors have presented data on a-c resistance and temperature rise of a compact form of double-channel copper bus carrying up to 7,000 amp, and have contributed new data pertaining to the heating due to currents induced by a-c buses in nearby structural steel members, both bare and embedded in concrete. Earlier researches established certain fundamentals and empirical rules based on tests at currents up to 5,800 amp. (Temperature Rise and Losses in Solid Structural Steel, O. R. Schurig and H. P. Kuehni. A.I.E.E. TRANS., v. 45, 1926, p. 184.) The present authors have not only extended the range of current, but have also presented comprehensive test data on iron heating due to 3-phase circuits, together with data pertaining to the design of copper short-circuit loops and grids for reducing the temperature rise in the steel members.

While the authors were primarily concerned with obtaining design information for a specific installation, their data on heating of steel and on means of preventing excessive temperatures in structural members covered a variety of conditions and will therefore be of value to others facing similar iron heating problems.

The skin effect resistance ratio of the special channel sections of approximately $1/2$-in. wall thickness in the double-channel hollow-square arrangement was 1.60 for the 6-in. channels, and 1.52 for the 8-in. channels at 60 cycles (based on data reported in Table I on p. 996 and on p. 998. Tubular conductors of corresponding dimensions would, as the authors point out, have somewhat lower skin effect, but would not necessarily run cooler than the channel structure unless effective internal ventilation were used.

The authors point out that the optimum wall thickness for a copper tubular conductor is approximately $1/2$ in., meaning that for a given outside diameter of tube, the one having a wall $1/2$-in. thick will have a lower 60-cycle resistance than other tubes of the same outside diameter but having thicker or thinner walls. In other words, the tube with a $1/2$-in. wall will carry more current for a given temperature rise than other tubes *of the same outside* diameter. It will be remembered, however, that the amount of copper used in the tube of $1/2$-in. wall will carry more current for the same temperature rise if built into a tube of larger diameter with a thinner wall.

If the same consideration is applied to the double-channel conductor it will be concluded that the channel of $1/2$-in. thickness does not use the copper as economically in respect to current carrying capacity as a larger channel with a thinner wall employing the same amount of metal. Unless, therefore, space is extremely limited and minimum over-all dimensions of channel structure are required, a channel of less than $1/2$-in. thickness will be the more economical in respect to the amount of metal needed to carry a given current at a given temperature rise. The actual thickness of channel to be selected will then be governed by such factors as mechanical strength and stiffness of channel beam structure, rolling limitations, and size and cost of clamps and fittings for supporting the structure.

It would be of interest to know how much the temperature rise of the channel bar structures would be increased due to proximity effect if the phases were in horizontal spacing, say 30 in. apart.

In Fig. 1 the clearance between the 2 channels forming the hollow square is shown as $5/8$ in. Did the authors determine how the current carrying capacity is affected by varying the clearance?

The interpretation and analysis of the data on inductive heating presented by the authors would be materially aided if a magnetization curve and resistivity data for the various steel members tested were available.

The temperature distribution curves shown in Figs. 3, 4, and 6 of the paper for various iron members crossing at right angles to a 3-phase circuit show clearly that the steel member has its highest temperature peak opposite one of the outside phases while the temperature opposite the other 2 phases is lower, the difference being as much as 25 per cent. Moreover the maximum temperature in the beam is shifted to the other outside phase when the phase rotation of the current is reversed. Since the explanation of the unsymmetrical heating is not an obvious one, the problem will be briefly discussed.

As a first approximation one might consider the beam replaced by 3 closed secondary loops, one under each of the phases, as in Fig. 6*a*. The voltages induced by the primary currents in the outside loops will then be found to be equal in magnitude but somewhat larger than that induced in the loop under the middle phase. These voltages would then induce circulating currents of equal magnitude in the 2 outside loops,

though the center loop would carry a smaller current since the average distance between this loop and the return conductors *A* and *C* is smaller than that for the outside loops.

It is seen that this analysis is far too rough to give even approximate results since it

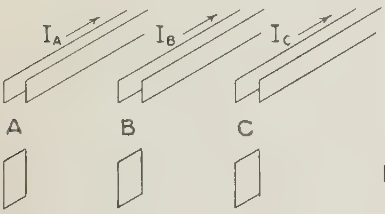



**Fig. 6a. Closed secondary loops under each phase**

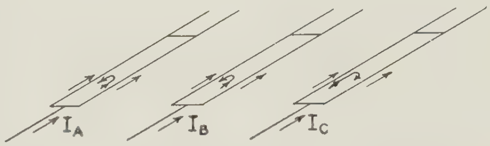



**Fig. 6b. Secondary loops formed by parallel members of each conductor**

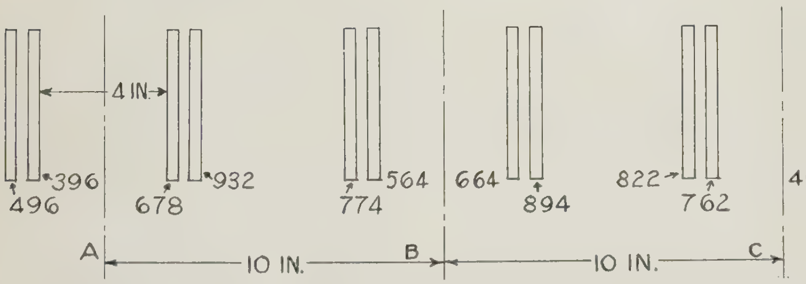



**Fig. 6c. Illustration of unsymmetrical current division**

does not take into account the voltages induced in each of the secondary loops by the circulating currents flowing in the other secondary loops. If, then, calculations of circulating currents are made taking into consideration the voltages induced in the secondary loops by all secondary currents as well as by the currents in the 3 buses, unequal currents will be obtained in the secondary loops under the outside phases.

A complete analysis of eddy current heating in the beam would of course involve considering induced currents in the iron due to both axial and transverse fluxes. Such a study will not be made at this time.

However, attention will be called to a related problem on which test data are available, namely, that of unsymmetrical heating and current flow in balanced 3-phase buses having 2 or more parallel conductors per phase. The multiple bar conductor like the iron beam has secondary short circuit loops linked by fluxes due to the currents in the 3 phases. In the multiple bar conductor the secondary loops are formed by the parallel members of each conductor, as indicated in Fig. 6*b*.

In the case of 2 members per phase as shown in Fig. 6*b*, there is a closed secondary loop in each phase, and, unless the plane of the loop is perpendicular to the plane of the conductors, induced circulating currents will flow around the loops. In the figure, for instance, the current induced in any one of the loops such as phase *A* will be determined by the voltages induced by the phase currents $I_B$ and $I_C$ as well as by the circulating currents in the loops of phases *B* and *C*.

The unsymmetrical current division is shown clearly in Fig. 6*c* based on measurements. It may be seen, for example, that the maximum current in the phase *A* group is 932 amp or about 13 per cent higher than the largest current in the phase *C* group, which is 822 amp, although on the basis of symmetry alone equal current components would be expected.

In Fig. 9 of the paper the authors have shown that the maximum temperature rise of a beam crossing a 3-phase circuit is less than that crossing a single conductor with return conductors remote, other things being equal. Likewise, the percentage differences between 3-phase heating and single-phase heating are shown to diminish with reduced spacing between conductors and iron members. The differences in question can be readily accounted for on the basis of the demagnetizing effect of the return conductors, which effect is present in the 3-phase arrangements shown but essentially absent in the single-conductor test with return conductor remote. Moreover, the percentage differences can be numerically estimated by calculating the resultant air field intensities at the center of the iron members and applying the empirical rules given in the 1926 A.I.E.E. paper already referred to.

The data presented by the authors in Figs. 16, 17, and 18 on reduction of inductive heating in various structural members by copper bands and grids indicate the effectiveness of the copper members, if properly applied, for lowering the temperature rise in the iron. The copper bands and grids have to be of sufficiently large section to prevent overheating of the copper bands themselves. The authors' data cover a sufficient range so as to permit selection of the proper members and their proper location in a variety of practical cases.

**V. R. Bacon:** Before commenting on the discussion, I wish to call attention to 2 omissions in the paper which should be corrected for the sake of completeness. The tests covered by Figs. 13 and 17 were made with 5,000 amp flowing in the conductors. This information was inadvertently omitted from the figures.

O. R. Schurig amplifies and clarifies the authors' reference to the $^1/_2$-in. optimum wall thickness for copper tubes and states that the interpretation of the test results would be simplified by a knowledge of the magnetic and resistance characteristics of the various steel members tested. The authors are in agreement with Mr. Schurig's treatment of the reference to optimum wall thickness. No information was obtained on the magnetic and resistance characteristics of the steel, since such data were not pertinent to the purpose of the tests.

Mr. Schurig also inquires concerning the variation of temperature rise with the spacing between buses and separation between channels. No tests were made to determine the effects of bus spacing or channel separation, since space limitations were the predominating influence in the bus design. However, some light on the effect of bus separation was contributed by F. R. Dallye in his discussion. His data are not strictly applicable to the sections tested by us, since the greatest increase of capacity found by Mr. Dallye corresponded to a separation providing a square formation. Separation of the copper channels beyond $^5/_8$ in. would have produced an oblong-shaped bus, which would have destroyed the symmetry with probably undesirable current distribution and consequent heating.

W. H. Hanna is interested in knowing the air velocities necessary to keep the bus cool and the effect of such cooling on the temperatures of nearby structural steel. He also inquires concerning the relative permeabilities and resistivities of the carbon and silicon steels tested.

No information on air velocities is now available since no tests were made and the design of the ventilating system has not yet been started. Data on the magnetic and electrical properties of the 2 steels were not obtained since the tests showed them to be unimportant as affecting the immediate problem.

The mathematical discussion contributed by H. B. Dwight probably accounts for a part of the temperature difference observed where a steel member crosses a 3-phase bus but his calculations would indicate lower temperatures in the middle phase than in either of the 2 outside buses, with expected lower temperature of the steel member at this point. This was not confirmed by tests. The effect of an interposed copper plate in reversing all relative temperatures of the outside points does not obviously follow Mr. Dwight's explanation.

The explanation of the shift of temperatures with phase reversal as given by L. A. Kilgore is logical, but we are not convinced that it contains the explanation in the case of the copper plate interposed between the bus and steel member.

Mr. Kilgore asks if the amortisseur bars were installed parallel to the isolated phase buses. No amortisseurs were installed along the main isolated phase buses during the tests described. The amortisseurs were in place only along the generator lead runs from the generator terminals to the isolated phase buses. These runs constitute a flat 3-phase system from the generator to the first or lower bus. Above the lower bus the amortisseur, with its end short circuited, forms 2 large open loops. Amortisseurs parallel to the main buses were not considered necessary because of the large

clearance between the buses and nearest conduits. Where structural members cross the main buses at right angles with close clearances, the steel is protected by short-circuited bands.

Mr. Kilgore brings out the fact that an amortisseur grid must carry material values of current in order to provide protection. This was confirmed in the field tests, where the cross section of the amortisseur grid was increased in order to avoid excessive losses in the amortisseur conductors.

The method of testing for resistance, as outlined by Messrs. Gorman and Forbes, is entirely logical but it would have involved a greater expense for testing equipment than was warranted. The limited background of this method of testing would render it open to the same objection as miniature tests; at least superficial confirmation would be required on full-sized sections.

# A Survey of Hydroelectric Developments

**Discussion and closure of a paper by the A.I.E.E. subcommittee on hydroelectric survey published in the June and July 1934 issues, p. 988–93 and 1086–94, and presented for oral discussion at the power generation session of the summer convention, Hot Springs, Va., June 29, 1934.**

**A. F. Bang:** Mr. Karpov and his committee are to be congratulated on the vast amount of statistical information presented on hydroelectric developments the world over. Much of the information is entirely new and the whole, it is believed, forms a more complete survey than any similar compilation yet published. Note in particular the interesting maps, Figs. 1 and 2, and accompanying tabulation of all major North American hydroelectric developments.

In our day with the continuous agitation for the development of our water power resources as a general panacea, and for doing this with public money almost regardless of whether the development is economical or not, it is highly instructive by means of such a survey to see water power—important as it is—being put in its proper place in relation to other sources of power and fuel. Take, for instance, Tabulation 2, which shows that in 1929 (the last year recorded) there was more animal power available in the United States of America than water power and over 110 times as much automobile horsepower. And if you consider this statement misleading due to the fact that water power largely is operating day and night and therefore produces relatively more energy than the other sources of power, take Tabulation 1, which shows that of the amount of energy produced in the world in 1927 from all sources, only 5.1 per cent was by water power. Such information is, indeed, surprising to many and would seem to warrant the continuation of such studies as presented here.

In his remarks introducing the statistical material, Mr. Karpov gives a somewhat sketchy outline of the main features that influence the economical development of water power. In one of his first paragraphs he points out that in several industries, notably electrochemical industries, the cost of power is such a large item that it may be economical to regulate the demand of power in accordance with the available supply of hydroelectric energy and gives several interesting examples of this. These cases, I believe, are rather exceptional. Usually, of course, industry demands continuous service in the quantity required whenever there is a demand for their own product. Mr. Karpov also stresses the influence of interconnections of utility systems on the economic development of water power. This is, undoubtedly, correct. The higher load factor obtainable in periods of high flow and the higher peak and stand-by service obtainable in periods of low flow of an unregulated river makes it economical to develop a greater part of the river flow when connected to a large system. An example of this can be had in the various developments on the Susquehanna River. Here 4 major plants were built from 1904 to 1931, as shown in Table I of this discussion.

**Table I—Susquehanna River Developments**

| Name | Start of Operation | River Flow Corresponding to Ultimate Plant Capacity |
|---|---|---|
| York Haven | 1904 | 12,000* |
| Holtwood | 1910 | 30,000 |
| Conowingo | 1928 | 70,000 |
| Safe Harbor | 1931 | 96,000 |

*Later by replacement of turbines increased to about 20,000 cfs.

All these plants have installed capacity several or many times the minimum river flow, but the interesting fact is that, although on the same river with the same available river flow, each successive plant was built for a larger ultimate utilization of the river flow, as illustrated in the tabulation. The cause is, no doubt, the changes in load available and visualized by the designers as time progressed.

One feature brought out by Table XI is interesting; namely, that so many hydroelectric plants in the United States are now from 20 to 30 years old, and apparently still going strong; this brings out the well-known sturdiness of the hydraulic turbines and the relatively slow obsolescence of the plants, which is one of the great economical advantages of such developments compared with other sources of energy.

**J. B. Crane:** In these days, when the theorists and economists are trying to run the country, it is quite essential that they have some basic facts to work on and our engineering societies can supply them without fear of being accused of spreading propaganda. Mr. Karpov and the subcommittee are to be congratulated on the preparation of this report and it will prove of importance to a great many interests.

The paper not only gives a condensed and very clear outline of the present status of hydroelectric developments, but also shows the part such developments take in our present economical system. From the data included in the survey it is clear that at present in the world as a whole and particularly in the United States the energy requirements are very manifold and extensive. These energy requirements are supplied by a number of sources. The combined energy drawn from all these sources is the base on which our present civilization is built. No one of the single sources of energy in itself can be considered of major importance. The diagram, Fig. 1, shows the relative importance of some of the energy sources. The prime mover capacity per capita of the different prime movers in the United States is shown from the years 1869 to 1929. So far as water power is concerned, not only the relatively small prime mover capacity per capita is to be noticed, but also the very slow increase of the per capita capacity as compared with the increase in the per capita capacity of prime movers in automobiles. The part of the total available prime mover capacity covered by water power is decreasing with surprising rapidity.

In Fig. 1 of the survey is shown how localized the developed water powers are, so that probably considerably less than one quarter of the area of the United States can be considered within the area influenced by the present developments and any possible in the future.

The tendency to consider water power as one of the major energy sources is based on a misinterpretation of the actual conditions. Water power, although localized, is important, but to a much smaller extent than many

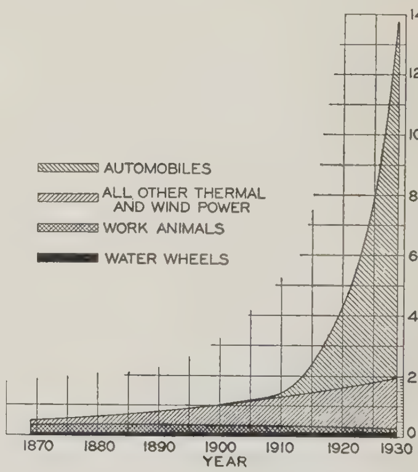



**Fig. 1. Horsepower per capita of prime movers installed in the United States**

other energy sources. It should be realized that no matter what efforts will be made the water power in the United States never can be expected to cover more than 5 per cent of the total energy requirements.

Figure 2 of the survey is of considerable interest, making clear the relative importance of the different drainage basins in North America and indicating the future power possibilities of the northern part of Canada. The fact that the St. Lawrence River drainage basin shows a larger aggregate development than the whole Pacific Coast, and the large total horsepower developed on the Atlantic Coast, are rather surprising.

The high state of present development of the south eastern part of the United States

in which the Tennessee Valley Authority is starting its operation indicates that this section of the country has done pretty well for water power supply even without government financed developments.

The method used in the survey to collect information on the aggregate horsepower capacity of all hydraulic turbines manufactured in the world should be commended. In no other way would it be possible to give such a complete picture of the relative importance of the different developments. That during the 5-year period 1928 to 1932 the medium head developments are still responsible for over 80 per cent of the developments in the United States and Canada and over 66 per cent in the whole world indicates that the Francis turbine, in one form or other, probably for many years yet to come will be the leading turbine of the world.

I hope the work of the committee can be extended to cover India and South America, where we have members of the Institute who have lived in those countries for many years and have there been identified with the hydroelectric developments, and I know will be glad to coöperate in every way possible.

**A. V. Karpov:** In connection with the diagram given in J. B. Crane's discussion, it is of interest to form a general picture of the importance of power in our present civilization.

Diagram, Fig. 2, shows the prime mover horsepower capacity per capita in United States, Europe, and mainland of Asia since

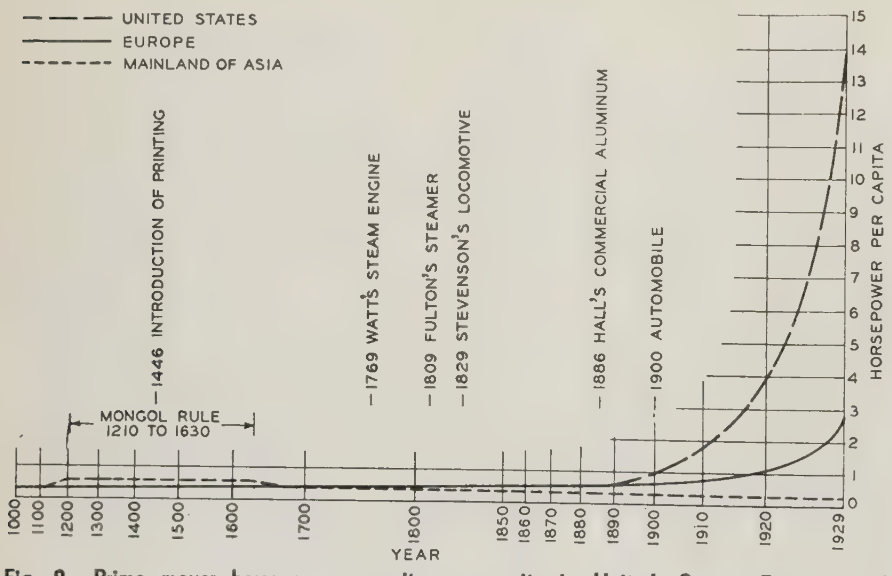



**Fig. 2. Prime mover horsepower capacity per capita in United States, Europe, and mainland of Asia since the year 1000 A.D.**

the year 1000 A.D., and gives an engineering representation of the cultural development of mankind during that time period. The data pertaining to the United States are fairly accurate. The data pertaining to Europe and Asia are less reliable and must be considered as reasonable estimates.

At the dawn of mankind, the amount of power represented by the human body was so nicely balanced that all the energy available had to be spent for the bare necessities of life. The first traces of advancement from the animal state are to be found when, due to tribe organization, the head of the tribe managed to put at his disposal the prime mover capacity of other members of the tribe. This gave him the opportunity to devote part of his time and energy to creative work, and laid the foundations of human civilization. For many thousands of years afterward the progress made by humanity was due to one kind or another of feudal system or slavery by means of which large prime mover capacities were put at the disposal of a few. Such organization did not increase the total amount of power at the disposal of mankind. The utilization of wind power and the introduction of work animals were the first and very timid efforts to increase the per capita prime mover capacity at the disposal of mankind. The Mongol rule of nearly 400 years' duration was based on an increase of prime mover capacity per capita due to very extensive use of horses.

From a modern point of view this increase of prime mover capacity per capita was very insignificant but at that time it was sufficient to create a domination by the Mongol races, which so far as the areas and the percentage of the total population of the world were concerned never was repeated.

About the beginning of the nineteenth century, after the human race had existed for a period of about 30,000 years, the conditions began to change radically in some parts of the world. Until that time there was no noticeable difference in prime mover capacity per capita in any part of the world. The work animals were the main source, the water and wind power next. The prime mover capacity of thermal movers started to enter into the picture with such rapidity that it is necessary to draw the diagram on a logarithmic scale to visualize the picture.

The curves of prime mover capacity per capita between the year 1800 and the present time represent the differences in the average state of civilization in the different parts of the world. At present the United States is in a stage of development that could not be predicted even 50 years ago. The prime mover capacity per capita is increasing with an amazing rapidity, indicating clearly the changes taking part. Europe follows at a much reduced rate. The mainland of Asia is stationary or even may be going backward.

The aggregate horsepower capacity of

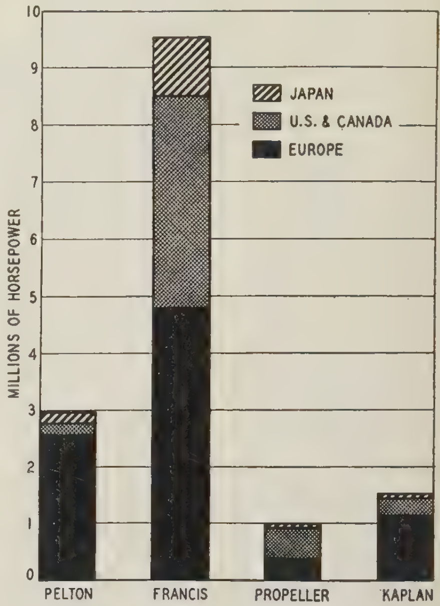



**Fig. 3. World production of hydraulic turbines, 1928–32 inclusive**

hydraulic turbines manufactured in the world mentioned in Mr. Crane's discussion is illustrated on the diagram, Fig. 3, which makes clear the tendencies during the past five years in Europe, United States and Canada, and Japan.

The conclusions drawn by Mr. Bang are of very considerable interest and importance. His table of the Susquehanna River developments gives the best illustration of the present tendency to improve the utilization of the available water flow.

## Calibration of the Sphere Gap

**Discussion and author's closure of a paper by J. R. Meador published in the June 1934 issue, p. 942–8, and presented for oral discussion at the instruments and measurements session of the summer convention, Hot Springs, Va., June 29, 1934.**

**P. L. Bellaschi** (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The recent contributions and discussions on the calibration of sphere gaps reveal the many aspects of this important subject. The writer wishes to discuss in particular certain interesting empirical relationships on the sparkover voltage of sphere gaps.

The following empirical expression can readily be derived from experimental data presented in a published article. ("Impulse Calibration of Sphere Gaps," P. L. Bellaschi and P. H. McAuley. *The Elec-*

*tric Journal*, June 1934. Mr. Vogel had previously established a similar graphical relationship from 60-cycle data. See his discussion, p. 1658, for the 60-cycle calibration of sphere gaps.) For a given ratio of sphere gap spacing $S$ to sphere diameter $D$, the ratio of sparkover voltage $E$ to sphere gap spacing $S$ can be expressed mathematically as:

$$\frac{V}{S} = A - B \log D \qquad (1)$$

where $A$ and $B$ are coefficients that are evaluated in the following from the experimental data. This linear relationship between $\frac{V}{S}$ and $\log D$ holds in particular for sphere gaps of sphere diameters, ranging from 12.5 to 200 cm. Inasmuch as the negative impulse and the 60-cycle flashover voltages of sphere gaps are substantially alike, the following analysis is for the present confined to the negative impulse and 60-cycle flashover voltages.

The coefficients $A$ and $B$ for various values of $S/D$ can readily be evaluated from the experimental data referred to. We have with a good degree of approximation:

| S/D | A | B |
|---|---|---|
| 0.1 | 34.9 | 4.4 |
| 0.2 | 33.5 | 4.4 |
| 0.3 | 32.0 | 4.4 |
| 0.4 | 30.2 | 4.4 |
| 0.6 | 26.8 | 4.4 |
| 0.8 | 24.2 | 4.4 |
| 1.0 | 22.2 | 4.4 |

Substituting in eq 1 the term $A$ as a function of $S/D$ the equation becomes

$$\frac{V}{S} = f\,(S/D) - 4.4 \log_{10} D \qquad (2)$$

From a practical standpoint, the next step would be to establish $f\,S/D$ as a simple mathematical function. Plotting $A$ against $\log_{10} S/D$ we thus obtain Fig. 1 of this discussion. We note the linear relationship from $S/D = 0.4$ to 1.0 inclusive and accordingly between these limits $A$ can be expressed as:

$$A = 22.2 - 20.3 \log_{10} S/D$$

Equation 2 then becomes

$$V = (22.2 - 20.3 \log_{10} S/D - 4.4 \log_{10} D) \qquad (3)$$

Table I of this discussion compares the sparkover voltages as given by eq 3 with the actual experimental values given in "Table II—Recommended Sphere Gap Calibration . . . ." of the paper previously referred to.

**Table I—Comparison of Sphere Gap Negative and 60-Cycle Sparkover Voltages From Eq 3 With Experimental Values**

| S/D | Sphere diameter, cm: 12.5 Eq | 12.5 Exp | 25 Eq | 25 Exp | 50 Eq | 50 Exp | 100 Eq | 100 Exp | 200 Eq | 200 Exp |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.4 | 127 | 126 | 242 | 239 | 456 | 454 | 830 | 863 | 1,620 | 1,630 |
| 0.6 | 164 | 165 | 308 | 308 | 577 | 579 | 1,074 | 1,080 | 2,000 | 2,004 |
| 0.8 | 195 | | 361 | 360 | 668 | 667 | 1,230 | 1,232 | 2,250 | 2,256 |
| 1.0 | 217 | | 402 | 395 | 736 | 728 | 1,340 | 1,340 | 2,420 | 2,430 |

Eq = Equation 3. Exp = Experimental values.

The agreement between the simple relationship given by eq 3 for the sphere gap sparkover voltage and the experimental data is good. The general relationship for sphere gap sparkover which is valid for all spacings is given by eq 2, where $S/D$ is evaluated from Fig. 1. The above relationships, which are derived from the experimental data, suggest the possibility of deducing the sparkover voltage of the sphere gap directly from fundamental considerations. At any rate, the sparkover data now made available should encourage studies of the kind.

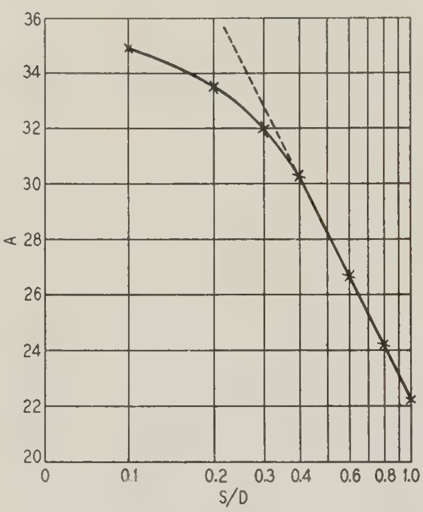



**Fig. 1. Curve of coefficient A as function of S/D**

**P. L. Bellaschi and Wm. L. Teague** (both of Westinghouse Elec. and Mfg. Co., Sharon, Pa.): Since the adoption of the sphere gap as a voltage measuring device 2 decades ago, the calibration of sphere gaps has been questioned frequently. With the advent of impulse testing the inadequacy of the sphere gap became manifest and subsequently it was possible to measure the inaccuracies involved in the present calibrations. An inherently fundamental method of impulse voltage measurement was developed at the Trafford laboratory in 1928 and in 1931 it was adopted at the new Sharon laboratory. Since the development of this fundamental method has contributed preponderantly to the correct measurement of impulse voltages, we wish to point out its essential features and also to compare the results obtained by this method of measurement for the calibration of sphere gaps on surge voltages to the data obtained by the method as outlined by Mr. Meador. ("Impulse Calibration of Sphere Gaps," P. L. Bellaschi and P. H. McAuley. *The Electric Journal*, June 1934. See also "Better Standards Needed for Surge Testing," F. D. Fielder. *Electrical World*, Sept. 30, 1933.)

This fundamental method of voltage measurement makes use of a resistance divider and a cathode ray oscillograph with accurately calibrated voltage plates.

The resistance divider consists of a noninductively wound low stray capacity oil-immersed resistor connected to a low-loss lead-covered cable which is terminated by a resistance equal to the cable surge impedance. The terminal resistance is located at the oscillograph and the deflecting plates are connected across the resistance.

Extensive laboratory studies ("The Measurement of High-Surge Voltages," P. L. Bellaschi. A.I.E.E. TRANS., v. 52, June 1933, p. 544) and experience have established the full reliability of the resistance divider. Direct comparison with the capacity divider has furnished convincing experimental evidence of its performance. The division of voltage is accomplished with strict proportionality and inappreciable distortion of wave form.

The oscillograph deflecting plates are calibrated on continuous voltages measured with either a conventional voltmeter or a D'Arsonval type milliammeter in series with a standard resistance. The continuous voltage supply must be smooth and free from ripples.

The sensitivity of the oscillograph deflecting plates remains essentially constant but frequent calibration and careful control of the cathode voltage minimize natural oscillograph errors. Table II gives the positive and negative voltage sensitivity of one of the cathode ray oscillographs. The sensitivity calibrations were made under identical conditions and over practically equal intervals of time during the period of one year. These calibrations indicate the full reliability of the cathode ray oscillograph when proper care is taken in its use.

For the calibration, the sphere gaps were set up to conform as nearly as possible with the A.I.E.E. requirements of Standards No. 4. The surge generator was carefully adjusted to give a smooth wave form, free from superimposed oscillations. The generator voltage was increased in small increments until sparkover of the sphere gap would occur approximately 50 per cent of the time, then several oscillograms for this voltage setting were taken. The average value of the voltage as scaled from these oscillograms gave the calibration for the particular gap and spacing used. This measured voltage was corrected proportionately to the relative air density to obtain the equivalent sparkover voltage at the standard condition of 25 deg C and 760 mm pressure. No measurable variations in the sparkover of sphere gaps with change in humidity were detected.

For a given gap setting, successive measurements of the voltage seldom deviate

from each other more than 1 to 2 per cent as indicated in published data. Repeated calibrations at different times with all conditions reproduced as closely as possible may deviate on the average 2 to 3 per cent. Since the accuracy obtained from the resistance divider and cathode ray oscillograph method is within 2 per cent, this indicates a possible variation in sphere gap performance greater than that in measurement.

Sphere gap calibrations for the 6.25, 12.5, 25, 50, 75, 100, 150, and 200-cm sphere gaps, based on the resistance-divider method of

**Table II—Calibration of Cathode Ray Oscillograph Voltage Plates**

| Calibration No. | Positive Voltage Sensitivity, Volts per Inch Deflection | Negative Voltage Sensitivity, Volts per Inch Deflection |
|---|---|---|
| 1 | 845 | 790 |
| 2 | 840 | 790 |
| 3 | 840 | 790 |

voltage measurement, are given in detail in the first reference given. A comparison between the Westinghouse and the General Electric companies' recommendations is given in Table III of Mr. Fielder's discussion. This comparison indicates a sufficiently close agreement for practical purposes between the 2 sets of data to enable an early revision of the present A.I.E.E. Standards No. 4.

The method of impulse voltage calibration of sphere gaps adopted by Mr. Meador is based, first, on a correct calibration of the 200-cm sphere gap to 60-cycle voltages up to 30-cm gap spacing; second, on the extrapolation of the 60-cycle calibration of the 200-cm sphere gap up to 50-cm gap spacing; and third, on the assumption, based on 60-cycle voltage polarity characteristics, that the 200-cm sphere gap calibration to impulse voltages is independent of polarity and identical for both impulse and 60-cycle voltages up to the 50-cm gap spacing. In this way Mr. Meador has calibrated the smaller sphere gaps by comparing them directly to the 200-cm sphere gap for both positive and negative impulse voltages. This method of impulse voltage calibration of sphere gaps is indirect when compared to the straightforward method using the resistance divider and calibrated cathode ray oscillograph. However, when carefully carried out, this indirect method is capable of good results as is indicated from the generally good agreement between the recommendations of the 2 companies for sphere gap calibrations.

**J. E. Clem** (General Electric Co., Schenectady, N. Y.): This paper by Mr. Meador should be of great value to the instruments and measurements committee in their study of impulse flashover and sphere gap calibrations. It also has what might be termed a by-product which should be of considerable interest to the operators. Mr. Meador has shown that the calibration curves previously in use have indicated too high a voltage. When the new calibration curves are used for insulation testing, a greater spacing will be used for the same indicated voltage, thus imposing a test on the equipment higher than that previously given. This will mean that the operators will be getting better equipment when the new calibration curves come into general use.

**F. D. Fielder** (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The calibration of sphere gaps is important because some laboratories have continued to base impulse data on sphere gap measurements. In addition, 60-cycle flashover values have been based on sphere gap calibration data. Apparently some of the A.I.E.E. sphere gap standards have been in error, as well as many of the calculated sphere gap calibration curves above the range covered by the A.I.E.E. standards. It is important to revise the present standards, and to extend their range as soon as satisfactory agreement can be reached.

The Westinghouse Company has been studying the characteristics of sphere gap calibrations for the past 2 years. Early results were presented in discussions at the A.I.E.E. 1933 winter convention, and later more complete data in the form of calibration curves were published in *Electrical World* for Sept. 30, 1933. Since then the data has been checked and extended, resulting in a complete presentation in *The Electric Journal*, June 1934. Briefly, the methods used involved an individual calibration of each size of gap by means of the cathode ray oscillograph and resistance divider, a cross check of results among 3 different laboratories, a further cross check by a direct comparison between gaps of different sizes, and finally an analytical development of the data. Reducing all results to a common basis with gradient curves decreased probable errors of measurement of individual points. As a result a complete table of recommended calibration curves of sphere gaps from 6.25 to 200 cm in diameter has been presented.

**Table III—Comparison of Westinghouse and General Electric Data**

| Gap Size, Cm | Positive Max. Diff., % | Positive Avg. Diff., % | Negative Max. Diff., % | Negative Avg. Diff., % |
|---|---|---|---|---|
| 200 | 2.5 | 1.4 | 2.5 | 1.6 |
| *200 | 6.1 | 2.6 | 3.6 | 2.3 |
| 100 | 1.8 | 0.8 | 1.5 | 0.6 |
| 75 | 1.9 | 1.0 | 2.8 | 1.8 |
| 50 | 4.5 | 2.2 | 6.2 | 3.3 |
| 25 | 2.5 | 1.4 | 2.6 | 0.9 |
| †12.5 | 2.7 | 1.3 | 2.7 | 2.1 |
| †6.25 | 5.3 | 3.3 | 5.3 | 3.1 |

* Based on extrapolated values.
† Spacing up to 1/2 diameter.

Since this paper also presents recommended calibration points for nearly all the standard sizes of sphere gaps, it is now possible to make a direct comparison between the Westinghouse and General Electric companies' recommendations. Comparison was made by noting the difference between each value as shown in Tables III to IX and the corresponding Westinghouse value as shown in *The Electric Journal*, June 1934, p. 231. The maximum differences and the average differences are shown in Table III of this discussion.

In general the agreement is good. The large percentage errors for the 6.25-cm sphere are caused by differences of only 2 kilovolts at low spacings. The large error in the 200-cm data is undoubtedly due to the methods of extrapolation, and would probably be reduced by actual tests. Westinghouse data are higher than General Electric data for about half of the points, with the variation the other way for the other half. Specifically, however, the Westinghouse data for the 50-cm gap are in all cases higher, and generally higher for the 75-cm gap. Westinghouse data are generally lower for the 200-cm gap and for the 25-cm gap. Particularly good agreement is found in the data for the 100-cm gap.

It is evident that the data are sufficiently close for practical purposes. An average of the 2 sets of data will yield curves which are accurate within the range of the accuracy of individual measurements. For purposes of standardization, however, it may be desirable to further study the data which are different by more than 2 per cent on the average. With the progress shown by the 2 groups of results, it appears likely that A.I.E.E. Standards No. 4 can be revised at an early date.

**R. E. Hellmund** (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The data presented in Mr. Meador's paper, together with those given by Messrs. McAuley and Bellaschi in the June 1934 issue of *The Electric Journal* and referred to in Mr. Fielder's discussion, represent a marked advance in high voltage testing technique. The material given is the result of extensive investigations in a number of the best equipped high voltage industrial laboratories in the country. Different methods of attack were used in the different laboratories, and in none of the cases can it be claimed that the methods employed were of sufficient accuracy for establishing an absolute primary standard. However, they are practical methods carried through with sufficient refinement to yield data accurate enough for most practical purposes. It must further be considered that aside from the testing methods, certain inaccuracies always enter into this work because of the fact that the relation of the spheres to surrounding and grounded objects cannot, in practice, be uniformly controlled. In view of all this, it is surprising that the results obtained are in such close agreement, and even better agreement undoubtedly can be obtained in the near future after some of the tests have been checked.

In view of the close agreement then expected, it would seem highly desirable to establish a new A.I.E.E. standard and to use as this standard the average of the results obtained in the various laboratories. Even with the average value of the present data, the following results will be accomplished:

1. Standard calibration curves for sphere gaps above 75 cm in diameter will be made available, filling a long felt need. Such curves will differ from the various data given here less than 1 per cent for spacings of less than 50 per cent of the sphere

diameter, and less than 2 per cent for spacings up to the sphere diameter.

2. The new curves will be available for the smaller sphere gaps and will correct errors in the present A.I.E.E. curves which are in the order of 4 per cent for spacings up to 50 per cent of the sphere diameter, and as high as 9 per cent for larger spacings. These corrections are large enough to be of practical importance and therefore are highly desirable. Again, it is found that for spheres of 25, 50, and 75-cm diameters the new curves would differ from the results of the different laboratories only about 1 per cent for spacings up to 50 per cent of the sphere diameter, and only in one case slightly over 2 per cent for the larger spacings.

3. The test results have established definite relations for surge testing with both polarities and indicate the desirability of carrying out most of the surge testing with spacings which are below 40 or 50 per cent of the sphere diameters. Such practice will naturally reduce the influence of surrounding and grounded objects, which are bound to be somewhat different in different laboratories.

It is believed that with the data now available and the plan as suggested, sphere gap calibrations sufficiently accurate for all practical engineering work will be made available. Insulation testing with 60 cycles and surge tests can hereafter be carried on with considerable confidence in the accuracy obtained, which is a marked step forward over the condition prevailing only a year or 2 ago. Any calibration of greater accuracy can be considered only of scientific value and importance, and work along this line should be left to laboratories of scientific institutions.

**C. M. Foust** (General Electric Co., Schenectady, N. Y.): Since its introduction some 20 years ago the sphere spark gap has been a most important part of the equipment of every high voltage laboratory. As a method of measuring high voltages the sphere gap has advantages which are not present in other measuring methods. Some of these advantages are as follows:

1. The simplicity of its construction permits the quick detection of defective arrangements.

2. Because the sphere gap depends for voltage indication upon the breakdown of an insulating medium, usually air, its use provides an immediate comparison of the dielectric strength of any insulation being tested with the strength of air. This air breakdown between symmetrical electrodes and within a field of uniformly distributed potential gradients has been found to vary but slightly. The conditions of voltage application, such as polarity, frequency, and wave shape, should be known if the sphere gap is used for measurement purposes.

3. The sphere spark gap measures directly all voltages at full amplitude. All the numerous problems involved in the design of an accurate and reliable voltage divider are eliminated by the use of the sphere gap.

4. The sparkover of the sphere gap is visible and audible. For demonstrating relative insulation strength the sphere gap has advantages over other methods which require supplementary measurements of circuit constants or development of films before values are available. An immediate indication of voltage level is obtained.

The disadvantages of the sphere spark gap are quite as definite and important as the advantages. Among these disadvantages are the following:

1. The unknown voltage must be repeated several times in making sphere spark gap measurements.

2. The sphere gap indicates only crest voltage and gives no indication of time elements involved or wave shape.

3. The sphere gap occupies considerable space, especially for high voltages.

4. Temperature, pressure, humidity, and ionization conditions affect the flashover of the gap slightly.

Other laboratory workers can undoubtedly describe additional advantages and disadvantages. As suggested in advantage 2, the sphere spark gap is in reality a calibrated insulation-breakdown device. Most measuring devices are based upon electromagnetic laws common to other types of electrical equipment, but the sphere spark gap sparkover as an insulation-breakdown has an electrical mechanism which is not well understood. No fundamental electrical laws which have been tested and demonstrated are available upon which to base calculated sparkover voltages.

The sparkover of the gap must be calibrated directly and for such a calibration some reference or basic method of voltage measurement must be available. At power frequencies the transformer ratio method has been used and it appears that the early sparkover values actually obtained by test were not in great error. Where extrapolations were resorted to at higher voltage levels and for larger sized spheres, however, errors were introduced. Also, the assumption that surge voltage sparkover for either polarity took place at the 60-cycle crest value over the range of spheres and spacings calibrated has been shown to be in error. But such errors had to do with lack of suitable calibrating facilities, not to anything erratic in the behavior of the sphere spark gap. This point should be carefully considered in estimating the future value of the sphere gap.

At present no absolute basis for sphere gap calibration on surges is available. It is quite possible to compare values obtained by sphere spark with those obtained by resistance divider and cathode ray oscillograph. Agreement between the 2 methods serves to establish confidence in results obtained. A great disagreement usually requires attention to and readjustment of the resistance divider and cathode ray oscillograph. The last named are complicated arrangements subject to a variety of difficulties and therefore must be given attention when they do not check the sphere gap. The method of calibrating the sphere gap wherein one sphere size is utilized as a reference basis has great value. However, much would be gained if a direct reference standard for surge calibration of sphere gaps were available. Lacking such a reference it is quite possible that good calibrations can be obtained through low frequency flashover data, intercomparison of flashover on various sized spheres, and comparison of results with those obtained by resistance or capacitance dividers and cathode ray oscillograph.

The practical laboratory man who must include a wide variety of kinds of surge testing in his daily work has no doubts concerning the value of the sphere spark gap. He cannot do without it. But he needs better calibrations and Mr. Meador has accomplished a worthwhile effort in assisting him to obtain them.

**G. D. Floyd** (Hydro Electric Power Commission of Ontario, Toronto, Can.): I would ask the author if he considered any alternative method for measuring the voltage to that using the rectifier and d-c milliammeter? It is very desirable when any calibration is made that the standard instrument have an accuracy better than the one being calibrated, and, if possible, both should be connected directly in the same circuit.

An instrument such as above described is available in Dr. Whitehead's corona voltmeter. It reads the crest value of voltage, as does the sphere gap, it is connected directly in the same circuit as the sphere gap, and it has an accuracy, when properly and carefully used, several times that claimed for the sphere gap. The 6.25-cm and 12.5-cm gaps could have been checked against an inexpensive type of corona voltmeter, and a calibration obtained against a standard dependent only on physical dimensions and air density.

I hope that if such a check test has not already been made, it will shortly be undertaken. The use of the sphere gap as a simple and, within limits, reliable instrument for measurement of crest values of high voltage has been extended greatly within recent years, and it is very necessary that its accuracy of calibration be established definitely against a standard of proved and unvarying constancy.

**W. A. Hillebrand** (University of California, Berkeley): Because of the urgent need for authoritative sphere gap sparkover voltages, the work of Mr. Meador and that of Mr. Bellaschi, as published in *The Electric Journal* for June 1934, is most welcome. The substantial agreement in results obtained by quite different methods is convincing proof of their accuracy. However, the differences, although relatively small, are important and it is to be hoped that they will be reconciled in the near future.

The sample data sheet recorded in Table I of the paper shows a spread of 4.5 per cent in the observations recorded. Differences of this order are due, at least in part, to residual charges on the spheres, as pointed out by Mr. Meador, and also, possibly, to error in the assumption that the electric breakdown strength of air in bulk is sufficiently constant to constitute what amounts to a primary standard. However, as again indicated by Mr. Meador, the data were obtained under the conditions of practical use in order that they might be directly applicable to the average laboratory.

In practice, the sphere gap is used to calibrate the testing transformer against the primary voltmeter. This means that, in making this calibration, there may be an uncertainty in any one reading of at least 2.25 per cent. I would like to ask Mr. Meador how many observations he considers it necessary to take in order to establish a reasonable average for the primary voltmeter reading that should correspond to the flashover of a given sphere gap setting. In obtaining this average, is it not reasonable to disregard "strays" that depart widely from the mean?

**W. L. Lloyd, Jr.** (General Electric Co., Pittsfield, Mass.): In Mr. Meador's paper reference is made to the calculated sphere gap curves upon which the A.I.E.E. calibration curves of 1914 and 1928 were based. I would like to point out an interesting fact in connection with such calculations. The formula for the sparkover voltage of the nongrounded sphere gap is ("Dielectric Phenomena in High Voltage

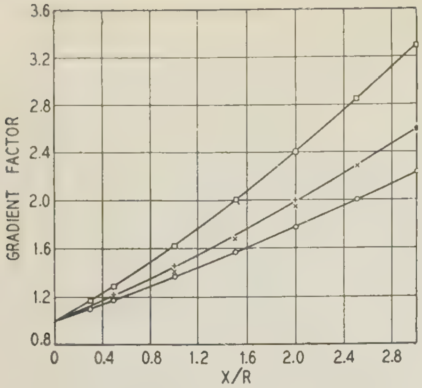



**Fig. 2. Sphere gap gradient factors**

□ = Calculated points
+ = Calculated points
× = Measured points
⊙ = Measured and calculated points

Engineering," F. W. Peek, Jr. Third ed., p. 27, McGraw-Hill Company, 1929),

$$e_s = \frac{g_s X}{f}$$

where $g_s$ is the apparent strength of air, $X$ is the length of the air gap, and $f$ is a factor which is found from theoretical considerations to vary with the spacing $X$ and the sphere radius $R$ in the following manner (Dean, *Physical Review*, December 1912 and April 1913, and *G. E. Review*, v. 16, 1913, p. 148. Peek, A.I.E.E. TRANS., v. 33, part 1, 1914, p. 923. See especially, Table VI on p. 930):

$$f = \frac{1}{4}\left(\frac{X}{R} + 1 + \sqrt{\left(\frac{X}{R} + 1\right)^2 + 8}\right)$$

Values of $f$ for different values of $X$ and $R$ are given in the lower curve of Fig. 2 of this discussion. Within the limits given in Mr. Meador's paper these values of $f$ are checked by measurements in the laboratory. That is, the measured and calculated values for the sparkover voltage of a given size and setting of sphere gap within the specified limits agree when the value of $f$ as indicated by the theoretical formula is used.

For the one side grounded sphere gap, however, the formula is:

$$e_s = \frac{g_s X}{f_1}$$

in which the present theoretical formula for the factor $f_1$ does not apply. The theoretical formula given by Dean and Peek is

$$f_0 = \frac{1}{2}\left(\frac{X}{R} + \sqrt{\left(\frac{X}{R}\right)^2 + 4}\right)$$

Values of $f_1$ for different values of $X$ and $R$ as indicated by this formula are given in the upper curve of Fig. 2, but these values are not checked by laboratory measurements. The values of $f_1$ required to be used to make measured and calculated values agree within the limits given in Mr. Meador's paper are given by the middle curve of Fig. 2. No theoretical formula has been derived to fit this middle curve but Royal Meeker and the writer have written an empirical equation which gives the required values of $f_1$ in terms of $X$ and $R$ for any size of grounded sphere gap. This formula is as follows:

$$f_0 = \frac{1}{3}\left(\frac{X}{R} + \frac{1}{2} + \sqrt{\left(\frac{X}{R} + \frac{1}{2}\right)^2 + 6}\right)$$

The close resemblance of this empirical equation with the 2 theoretical formulas is striking. The theoretical reason for this would be interesting as the resemblance seems more than a mere coincidence.

**J. T. Lusignan, Jr.** (Ohio Brass Co., Barberton): There are a few factors relating to sphere gap sparkovers which I should like to bring up in connection with Mr. Meador's work.

I would like to ask Mr. Meador if, in his work with sphere gaps, he has found a condition wherein the breakdown values for the first few sparkovers on a given sphere gap are appreciably lower than those obtained later during the same test. I believe that several previous investigators (Carroll and Cozzens, A.I.E.E. TRANS., January 1929, p. 1) have found this sphere gap behavior. It has generally been attributed to a surface condition of the spheres rather than to anything in the intersphere space. I believe that in some cases this has occurred even though some care had been taken to clean the spheres beforehand. My reason for bringing this up here is that I feel some mention should be made in any revised sphere gap testing standards in regard to the care necessary in preparing sphere surfaces for sparkover measurements. Undoubtedly, more or less of an attempt is made in all laboratories to clean sphere electrodes before their use, but some sort of an authoritative statement in a sphere gap testing standards, giving the necessary surface preparation, would be of value. This would tend to eliminate erroneously low sparkover values when tests are being made to meet customers' specifications. Often the customers' inspectors take cognizance of such low values, particularly when only a few measurements are made, so that there should be some standardized procedure which will prevent such low values, or else allow them to be corrected for if they are inevitable.

As Mr. Meador states, the existence of a polarity effect in sphere gaps has been known for some time. Dr. Reukema gave an interesting theoretical analysis suggesting the reason for this polarity effect in sphere gaps in a discussion published in the A.I.E.E. TRANS., January 1929, p. 257.

In calibrating the high voltage transformer sets at our Barberton laboratory we have found appreciable inconsistencies when plotting the voltage values obtained with different diameters of the spheres, using the recognized sphere gap calibration curves. As a rule, the larger the spheres the lower would be the measured values on the high voltage side for a given voltmeter coil reading. It seems that this might be caused by 2 factors: first, curves from theoretical calculations do not take into account the probability of more impurities being present on the surfaces of and in the space between large spheres than would be the case with smaller spheres; second, the stored condenser energy for energizing approaching streamers would be greater in the case of the larger spheres due to their greater electrode areas and shorter spacings for the same voltage settings.

The polarity effect present in sphere gaps is inherently due to the asymmetrical electrostatic field introduced as soon as one sphere is grounded. Obviously, the greater the clearance of the spheres from the ground the less the field dissymmetry. For this reason any new standards for sphere gap testing should specify ample clearances, particularly for the larger sphere gaps. It is possible that some of the differences now found among 60-cycle insulator flashover measurements of various laboratories may be due to the fact that voltage calibrations are taken with sphere gaps mounted in different manners. For example, the polarity effects of the same size of spheres mounted in a frame, hung from a roof, and supported out from a wall may all be sufficiently different to cause appreciable variations in flashover measurements on the same type of insulators having consistent polarity characteristics.

**K. B. McEachron** (General Electric Co., Pittsfield, Mass.): To measure high voltages accurately requires some form of measuring device which can be calibrated with reasonable accuracy. As the paper indicates, the calibration of a sphere gap cannot be accomplished by direct means in the present state of the art, and must necessarily be accomplished through the use of some method of triangulation.

The sphere gap is convenient to use, and for many laboratories which are not equipped with cathode ray oscillographs it represents the only method available for checking high potentials, either transient or periodic. Therefore the calibration of the sphere gap is important, and the changes which Mr. Meador has indicated represent a sufficient deviation from the A.I.E.E. standard curves that a revision of the A.I.E.E. standard values should be undertaken.

Laboratories, particularly those in colleges, make use of small sphere gaps at small settings for the measurement of both transient and low frequency potentials, and it is very desirable, therefore, that further study be made of the smaller sphere gaps so that data, corresponding to that given by Mr. Meador, will be available for the smallest sphere gaps in use. In this connection, it should be remembered that the use of ultra-violet light with small sphere gaps is very useful in reducing the time lag and making sparkover values more consistent. The use of ultra-violet light was found useful by the writer in connection with "The Measurement of Transients by the Lichtenburg Figures," presented to the Institute in 1926, where light from an arc lamp was used. More recently the mercury vapor lamp has been used successfully.

The good check obtained between the results given by Mr. Meador and those reached by Mr. Bellaschi, as appearing in the June 1934 issue of *The Electric Journal*, serves to inspire confidence in the results obtained by both of the investigating laboratory groups. This is particularly true since quite different methods were used in arriving at the results.

Since the use of the resistance divider has been a matter of some discussion, it seems desirable to introduce here a brief

discussion of the history of the dividers and their use.

In the first published use of the cathode ray oscillograph in the United States, for the purpose of measuring single transients, a capacitance divider was described. ("Study of Time Lag of the Needle Gap," K. B. McEachron and E. J. Wade. A.I.E.E. Trans., 1925, p. 832.)

The capacitance divider in this form is not suitable for high voltages, because of the necessity of locating the divider at some distance from the cathode ray oscillograph.

In 1925, Mr. Wade developed a so-called compensated resistance divider for use up to 100,000 volts, which really consisted of a bridge circuit with resistance in 2 arms and capacity in the other 2 arms. This resistance divider was first described in *Electric Light and Power*, May 1929.

In 1927, Gabor described a cable divider and gave the theory of its operation. ("Forschungshaft der Studiengesellschaft für Hochstspannung - spanlagen"—1. Heft. Sept. 1927, p. 42). By the proper circuit arrangements, the cable may be used with a resistance divider, and reproduces, with reasonable accuracy at the receiving end, the transient applied at the entering end. The cables used are not absolutely distortionless, but are sufficiently good for the work to be done, providing the proper precautions are taken.

Since Gabor introduced the resistance-cable divider, its use has spread until most laboratories today are familiar with its use and have found it a very helpful circuit arrangement for the measurement of extremely high voltages.

**F. O. McMillan** (Oregon State College, Corvallis): It is indeed, gratifying that progress is being made in the general recognition of the 60-cycle polarity characteristics and the difference in the positive and negative calibration of the sphere gap.

In October 1929, J. T. Lusignan, Jr., presented his paper "A Study of High Voltage Flashovers" (A.I.E.E. Trans., v. 48, 1929, p. 246–54) in which he described some 60-cycle research work done in the Harris J. Ryan high voltage laboratory. In his paper he called attention to the observation that a 50-cm grounded sphere gap at diameter separation always flashed over when the upper ungrounded sphere was negative, and at 69 cm separation flashovers occurred at both polarities. At the larger sphere spacing he observed about twice as many positive as negative flashovers.

In September 1930, we reported the results of research work at Oregon State College in a paper "The Influence of Polarity on High Voltage Discharges" (A.I.E.E. Trans., v. 50, 1931, p. 23–33). In this paper complete characteristics were shown graphically using the percentage of the 60-cycle sparkovers that were positive as ordinates, and the sphere gap spacing in centimeters as abscissas. These curves were called "Polarity Distribution of 60-Cycle Sparkovers," and they are identical with those Mr. Meador has called "60-Cycle Polarity Characteristics." Complete curves were shown for a 6.25-cm sphere to plane gap and for 2.54-cm and 6.25-cm sphere gaps. The 25-cm sphere gap characteristic was shown up to 10-cm spacing which was the limit of the 60-cycle voltage available. The sphere gap curves all show the same general characteristics. See Figs. 9, 10, and 12 of the paper referred to. At close spacings sparkover was found to occur on both polarities, at intermediate spacings sparkover occurred only when the ungrounded electrode was negative, and at somewhat more than diameter spacing a rapid transition from 100 per cent negative sparkover to 100 per cent positive was found.

Mr. Meador shows in Fig. 3 a 60-cycle polarity characteristic for a 6.25-cm sphere gap that has a rather high percentage of positive sparkovers occurring over the entire range of spacings up to 8 cm. This is not in agreement with our findings. For the past 4 years the determination of the 60-cycle polarity characteristic for either a 6.25- or 12.5-cm grounded sphere gap has been one of our regular high voltage laboratory experiments. This laboratory work has given an opportunity to obtain the data for and examine a number of characteristics for the 6.25-cm sphere gap. During the past year E. D. Harrington and K. M. Klein, seniors in electrical engineering, made an extended investigation of the influence of the ground plane position on the 60-cycle polarity characteristic of the 6.25-cm sphere gap. The gap was placed at various distances above the ground plane ranging from 1 to 20 sphere diameters. Over this large variation in ground-plane relationships, a definite range of gap spacings in which no positive sparkovers were obtained was always observed. The extent of the range of sparking distances over which no positive sparkovers occurred was changed by the position of the gap with respect to the ground plane, but a definite range always remained in which all of the sparkovers were negative. It is, therefore, our belief that the 60-cycle polarity characteristic shown in Fig. 3 was obtained as a result of some extraneous cause not directly related with the polarity characteristic of the 6.25-cm sphere gap.

We have observed that it is absolutely necessary to have the circuit free from corona discharges of any magnitude when these characteristics are taken on gaps with small diameter spheres, because the transient disturbances in the circuit voltage caused by corona will completely upset the polarity distribution of the sparkover on such gaps. The reason corona discharges cause more trouble on small gaps than on large ones is obvious when consideration is given to the fact that the voltage disturbances caused by corona constitute a much greater percentage of the total voltage when the relatively low sparkover voltages for small sphere gaps are involved. Because of this, and further, because over a period of 4 years under widely different conditions it has been possible to consistently obtain typical 60-cycle polarity characteristics for both a 6.25-cm sphere gap and also for a smaller 2.54-cm gap, we are convinced that the 60-cycle polarity characteristic shown in Fig. 3 is not the true characteristic for a grounded 6.25-cm sphere gap. It is believed that the data in Table V and Fig. 10 of our 1930 paper are more nearly representative of the 60-cycle polarity characteristic of the 6.25-cm sphere gap. The corona disturbance may also account for the fact that the 60-cycle test curve in Fig. 3 is lower than the calculated curve and not in as good agreement with it as the experimental curves obtained for the 12.5- and 25-cm sphere gaps which gave normal 60-cycle polarity characteristics and were in quite good agreement with the calculated curves.

In the 1930 paper it was pointed out that the phenomenon of sparking over on 60-cycle symmetrical voltage only when the spheres have a definite polarity relationship with respect to ground showed conclusively that the positive and negative sparkover voltages must be quite different for the sphere separations that select one sparkover polarity continuously, otherwise grounded sphere gaps would spark over on either polarity indiscriminately for all sparking distances. Tabulated data and curves were presented which showed that the unidirectional impulse sparkover characteristics of the sphere gap gave excellent correlation with the 60-cycle data. See Tables VI and VIII and Figs. 11, 13, and 14. These data were obtained by taking advantage of the fact that, at close spacings, the sphere gap has no appreciable polarity effect, and, therefore, a large sphere gap may be used for the impulse voltage calibration of a smaller gap.

At relatively short sphere gap sparking distances no appreciable difference was found in the positive and negative impulse sparkover, at intermediate spacings the sparkover voltage was lower when the ungrounded sphere was negative than when it was positive, and at long sparking distances (more than one sphere diameter for the spheres investigated), the negative sparkover rapidly approached the positive value, became equal to it, and finally increased to a considerably larger value. The complete impulse characteristic for the 6.25-cm sphere gap is shown in Fig. 11 of the 1930 paper. These data showed clearly that for the smaller sizes of spheres, for which accurate experimental 60-cycle calibration data were available in the A.I.E.E. Standards, the crest a-c calibration curves were quite accurate for impulse voltage measurements when the ungrounded sphere was negative, but the positive values of voltage obtained by the use of the 60-cycle curves were much too low. The latter was especially true when voltages were measured near the maximum recommended sparking distance for a particular size of spheres. The maximum differences observed between the positive and negative sparkover voltages were very much larger than the permissible errors of measurement in high-voltage testing.

The impulse characteristics obtained had the same general characteristics as those found by Mr. Meador. The principal variation is in the magnitude of the difference in the positive and negative sparkover voltages and the point at which the positive and negative curves cross. The only impulse characteristic Mr. Meador has carried up to the cross-over point is shown in Fig. 15, which is for the 12.5-cm sphere gap. These curves cross over at 10 cm gap spacing or only 80 per cent of sphere diameter. It is rather surprising that the cross-over occurs at such a small sphere separation. This is particularly true in view of the fact that the 60-cycle polarity characteristic

in Fig. 4 does not show any appreciable percentage of positive sparkovers at 15 cm spacing or 120 per cent of sphere diameter separation. We have found better correlation between the 60-cycle polarity characteristic and the impulse characteristics for the 6.25-cm sphere gap. See Figs. 10 and 11 of the 1930 paper. For this sphere gap the transition from negative to positive sparkovers on the 60-cycle polarity characteristic starts at 144 per cent of sphere diameter separation, and the impulse characteristics cross over at a separation of approximately 134 per cent of sphere diameter. Mr. Meador is not recommending the use of the sphere gaps in this range of sizes beyond a spacing of 50 per cent of the sphere diameter; nevertheless, it is believed the complete characteristics are a good index of the extraneous influence present at the time the characteristics were taken and, therefore, constitute a measure of the reliability of the calibration data.

There is considerable evidence that the sphere gap is influenced by extraneous fields and grounded objects to a much greater extent than has heretofore been recognized. It would, therefore, appear that these influences should be studied and the conditions under which the sphere gap is to be used specified in a great deal more detail in any future standards than are adopted.

**L. N. Robinson** (consulting engineer, Corning, N. Y.): A sphere gap is essentially a center-zero voltmeter which is used in an electrostatic field whose intensity depends on the voltage being measured. Each body of insulating material and each body of conducting material which is in the vicinity of the sphere gap distorts the electrostatic field and produces more or less "proximity effect" on the sphere gap. If the combined proximity effects of neighboring bodies are the same on both spheres, the scales on both sides of the zero are affected alike or, we may say, the calibration curve is shifted as a whole. If the combined proximity effects of neighboring bodies are greater on one sphere than on the other, there will be an "apparent" polarity effect because the scale on one side of the zero will be affected more than that on the other side.

Therefore, it is necessary to define the spheres, their supports and especially their surroundings in specific detail for a primary standard sphere gap before it can be assumed that a standard calibration curve will apply. Sphere gaps which are not primary standards should be provided with individual calibration curves.

Mr. Meador and others have observed apparent polarity effects in vertical sphere gaps, but we find no evidence that polarity effects are inherent in sphere gaps in general.

Vertical and asymmetrical sphere gaps may manifest polarity effects which are actually proximity effects or due to vertical drafts of air which would act equally on both electrodes of a horizontal, symmetrical sphere gap. The heating of the dielectric prior to sparkover causes some upward draft, and there will be vertical drafts in the room if there is much temperature difference between the floor and the ceiling.

There is no reason to imagine that a horizontal sphere gap, in which identical spheres are symmetrically supported by identical insulators and equidistant from each extraneous body, will manifest any polarity effect.

Mr. Meador states that, during his tests, "the height of the grounded sphere above the floor was maintained at from 3 to 5 diameters." With reference to polarity effect, he says: "The large ground surface near the grounded sphere is the upsetting factor." Evidently, the clearance of 3 to 5 diameters did not eliminate the proximity effect of the floor. However, the effects of vertical drafts of air and the proximity effect of the floor could have been equalized with respect to both spheres so as not to have produced any polarity effect if the centers of both spheres had been on a line parallel with the floor and the spheres supported by identical insulators.

There does not appear to have been any inherent electrical characteristic which brought vertical sphere gaps into use. The preference seemed to be due to the apparent cheapness of wooden frames for supporting medium-sized spheres before the possible polarity effects of the asymmetrical frames were recognized.

The needle gap was, and is, practically always of the horizontal type. In fact, early sphere gaps consisted of spheres with thin shanks which were mounted in place of needles in horizontal needle gap stands.

Since impulse tests of high voltage insulations are very essential and polarity effects in sphere gaps can hardly be tolerated, the polarity effects, which appear to be unique in vertical sphere gaps, may be a very good reason why horizontal sphere gaps should be adopted as standard or, at least, for primary standards.

**F. J. Vogel** (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The inaccuracy of present sphere gap calibrations in 60-cycle measurements and the relationship between the 60-cycle and negative surge calibrations are the high spots of this investigation.

In past years the writer has had occasion to design numerous testing transformers. There was a demand for accurate indicating voltmeters, and the production of pure sine waves for testing. Several equipments were sold with guarantees as to the accuracy of voltage measurement. At that time, the process was reversed; that is to say the fact that the meter checked the sphere gap readings was taken as proof that the meter was satisfactory and the guarantees met. It should be noted that the tests were made on commercial designs, with no thought of finding sphere gap inaccuracies, and my object in reporting them is to confirm Mr. Meador's data, in general, and point out slight conflicts in some cases.

In 1925, the Westinghouse company furnished 2 testing equipments, one for 500 and one for 750 kv. These were made using 2 and 3 units in cascade, respectively. The transformers were of comparatively large capacity, and accordingly the regulation should be negligible. Further, since the magnetizing current was relatively small, no reason can be seen, nor was in fact found, for error due to cascade connection. The performance of the voltmeter coil and several sphere gaps was quite carefully checked.

**Table IV—Calibration of 25-Cm Sphere Gap**

| Sphere Gap Setting, Mm | Voltage From Voltmeter Coil, Kv rms | Voltage, Present A.I.E.E. Std., rms |
|---|---|---|
| 1 Unit | | |
| 38.2 | 74.6 | 75 |
| 53.3 | 99.5 | 100 |
| 69.9 | 124.0 | 125 |
| 88.0 | 150.0 | 150 |
| 129.9 | 192.0 | 200 |
| 2 Units in Cascade | | |
| 53.3 | 97.0 | 100 |
| 88.0 | 147.5 | 150 |
| 129.9 | 195.0 | 200 |
| 191.0 | 237.0 | 250 |

Instead of using a crest voltmeter to obtain the voltmeter coil voltage, a sine wave was maintained at the transformer terminals, the ratio between the crest and the root mean square values being $\sqrt{2}$ within 2.2 per cent.

A tabulation of the results obtained with the 25-cm gap is given in Table IV of this discussion.

At that time, an effort was also made to obtain data with a 50-cm gap at higher voltages, but the gap was not strictly in accordance with A.I.E.E. standards, and a comparison with the 25-cm gap (Fig. 3) made us fearful of its accuracy or the possibility of a check. It also made the accuracy of the 25-cm gap doubtful above 200 kv.

Later the 3 units were set up in the customer's plant, and a check with a 100-cm gap was possible. Unfortunately, this gap, being horizontal, is not quite in accordance with A.I.E.E. rules, but since the openings used were comparatively small, it is believed that it is accurate.

A tabulation of the data taken on the meter sphere with 1, 2, and 3 units is given in Table V.

From this data it may be seen that the present 25-cm gap calibration has been found reasonably accurate, but that variations might be expected above half opening. Likewise, it seems that voltmeter coils in

**Table V**

| Sphere Gap Setting, Cm | Voltage From Westinghouse Curves, Kv rms | Voltage by Voltmeter, Rms | Coil, Kv Crest | Interpolated Values From Meador's Recommended Calibration Table IV, Kv Crest |
|---|---|---|---|---|
| 1 Unit | | | | |
| 10.7 | 200 | 202 | 286 | 288 |
| 13.6 | 250 | 250 | 354 | 352 |
| 2 Units | | | | |
| 10.7 | 200 | 196 | 277 | 288 |
| 13.6 | 250 | 250 | 354 | 352 |
| 23.1 | 400 | 389 | 550 | 566 |
| 3 Units | | | | |
| 13.6 | 250 | 242 | 342 | 352 |
| 23.1 | 400 | 384 | 542 | 566 |
| 53.0 | 750 | *610 | *995 | 1,018 |

* For previous data, the wave shape was closely a sine wave. Distortion in generator voltage wave present in this reading was checked by oscillograph and wave analysis. The crest factor was found to be 1.63 instead of 1.41.

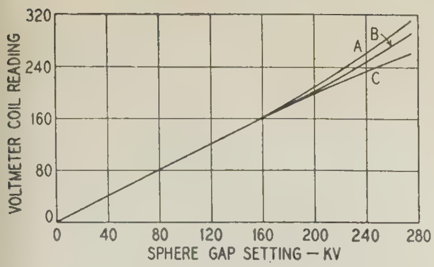



**Fig. 3. Comparison of sphere gap readings**

A. 25-cm gap in parallel with 50-cm gap
B. 50-cm gap
C. 25-cm gap taken alone

cascade units, with proper characteristics, unless the wave shape is poor, can also be used to measure voltage to a fair degree of accuracy. It may also be seen that the meter sphere gap calibration curves as used by the Westinghouse company are substantially correct.

Later, 2 units for 350 kv in cascade were calibrated. These units furnished data for the 50-cm sphere as well as the 25-cm sphere. For purposes of simplicity comparison is made by tabulating the sphere gap voltage, corrected in line with the present A.I.E.E. standards, and the voltmeter coil voltages.

| Data With 25-Cm Gap | | Data With 50-Cm Gap | | |
|---|---|---|---|---|
| Sphere Gap Voltage, Kv rms | Voltmeter Coil Voltage, Kv rms | Sphere Gap Voltage, Kv rms | Voltmeter Coil Voltage, Kv rms, Unit No. 1 | Voltmeter Coil Voltage, Kv rms, Unit No. 2 |
| 50 | 49.2 | 58.8 | 60.8 | 59.5 |
| 75 | 75.0 | 98.0 | 100.6 | 99.5 |
| 100 | 100.7 | 122.5 | 124.8 | 122.8 |
| 125 | 126.0 | 147.0 | 147.5 | 144.5 |
| 150 | 150.3 | 171.5 | 169.0 | 164.0 |
| 175 | 174.7 | | | |
| | | **Units 1 and 2 in Cascade** | | |
| | | 172.5 | 173 | |
| | | 197.0 | 198 | |
| | | 247.0 | 249 | |
| | | 296.0 | 294 | |
| | | 345.0 | 342 | |

To sum up, data taken both the single units and with units in cascade confirm the present A.I.E.E. standards for the 25- and 50-cm gaps. The calibration curve as used by the Westinghouse company for the 100-cm gap is also checked. Further, due to the effect of surroundings it is seen that variations in spark gap readings occur at openings over 1/2 the sphere diameter and it is recommended that for precise work gap openings over 1/2 the sphere diameter should not be used.

Acknowledgment is hereby made of the work of J. K. Hodnette and W. L. Teague in obtaining some of the data here presented.

**J. R. Meador** (General Electric Co., Pittsfield, Mass.): Referring to Messrs. Bellaschi's and Teague's discussion of their method of measuring impulse voltages, 3 methods of voltage measurement were considered for the impulse tests reported in this paper. These alternatives were: 1, the capacitance divider with cathode ray oscillograph; 2, the resistance divider with cathode ray oscillograph; and 3, a sphere gap calibrated by voltmeter coil measurement on 60 cycles and used, in the range where its polarity effect was negligible, as a standard for the impulse distribution of the other sizes of spheres.

The third method of voltage measurement was used because: 1, a testing transformer with a voltmeter coil of high accuracy was available; 2, it was believed that the 60-cycle polarity characteristic gave a sufficient indication of the impulse polarity effect; 3, by using one sphere gap as a reference, all of the sizes of spheres should agree on voltage indications; and 4, it was felt that there was not sufficient proof of the accuracy of the capacitance and resistance dividers to permit their use in the determination of sphere gap calibrations.

With regard to the comparison between the General Electric and the Westinghouse data given by Mr. Fielder, I believe that in general the agreement is very good. The maximum differences in the 200-cm sphere gap curves are at spacings in which both sets of data are obtained by extrapolation. The differences in the 50-cm sphere gap curves are hard to explain, however. When taking the General Electric data, the 50-cm spheres were compared with the 100-cm spheres. Then, the 50-cm spheres were used for a comparison with the 25-cm spheres. The agreement between the General Electric and the Westinghouse calibrations of the 100- and 25-cm sphere gaps is excellent, whereas the agreement on the 50-cm spheres is only approximate. I would suggest that Mr. Fielder compare his 25-, 50-, and 100-cm sphere gaps in the manner described above in a search for possible errors. A further check may be obtained by taking a 60-cycle calibration of the 50-cm sphere gap up to a spacing of one diameter. I feel confident that these discrepancies can be reduced by coördinated efforts between the 2 groups of investigators.

I hesitate to draw any definite conclusions from the 60-cycle data presented by Mr. Vogel. The sparkover data on the 50-cm sphere gap show an average difference of 2 per cent between 2 different testing transformers. Furthermore, there is the possible error of 2.2 per cent due to variation in wave form. I do not agree that there are appreciable variations in sphere gap readings on 60-cycles above 50 per cent of diameter spacing. When properly calibrated, the sphere gap may be used with confidence up to a spacing of one diameter if a reasonable clearance is maintained. The only data points above 50 per cent of diameter spacing shown by Mr. Vogel are taken with 2 or more testing units in cascade. Under this condition the error in each unit is cumulative and a high degree of accuracy is not to be expected.

Mr. Bellaschi's empirical equation for sphere gap sparkover voltages is very interesting and may lead to more study of the fundamental mechanism of sparkover. However, for the present, it is very doubtful that calculated sphere gap sparkover curves will be well received by laboratory men in view of their past experience with them.

Mr. Bellaschi uses the gradient curves from the paper that he mentions ("Impulse Calibration of Sphere Gaps," by P. L. Bellaschi and P. H. McAuley, *The Electric Journal*, June 1934) in deriving his empirical equation. Referring to this paper, I erroneously assumed at first reading that the points on the gradient curves of Fig. 14 were actual test points or, at least, points taken from the curves drawn through an average of the test points. On closer inspection of the sparkover curves given on Figs. 4 to 11 inclusive, however, it is obvious that there are discrepancies. On Fig. 7 the negative polarity curve for the 75-cm sphere gap is drawn through 10 test points. At diameter spacing the average gradient is 13.2 kv per cm, whereas this point on Fig. 14*a* is plotted as 13.85 kv per cm—a discrepancy of 5 per cent. Similarly, at 80 per cent of diameter spacing, a discrepancy of 3 per cent exists. The 100-cm spheres at diameter spacing, both polarities, show changes of 2 per cent. I would expect some isolated test points to vary this much from an average sparkover curve but once the curve is drawn, it does not seem advisable to change it to agree with a gradient curve having no fundamental basis.

The corona voltmeter mentioned by Mr. Floyd was not used in this investigation. It should prove very useful in obtaining accurate calibration curves for small sphere gaps.

Mr. McMillan emphasizes the effect of ground and extraneous fields on the 60-cycle polarity characteristics of sphere gaps. The lack of agreement on the 6.25-cm sphere gap between his previously published data and that reported in this paper may be due to such causes. As stated in the paper, the 6.25-cm sphere gap was tested entirely in accordance with present A.I.E.E. recommendations as to distance above ground, size of frame, and distance from nearby line and ground potential surfaces. A series resistance was used in the line lead. The tests were made under the same conditions that would occur for normal use of the sphere. It is encouraging to learn that the important work reported by Mr. McMillan in 1930 is being continued.

Mr. Robinson is undoubtedly correct in assuming that the polarity effect of vertical sphere gaps mounted near the floor is really a proximity effect that produces an asymmetrical field. The use of horizontally mounted spheres would be very cumbersome under average laboratory conditions where floor space is at a premium. A complicated supporting structure would be necessary for spheres of the order of 100 and 200 cm in diameter. The objection to the polarity effect of vertical sphere gaps should be eliminated if calibration curves are taken on both polarities.

Professor Hillebrand's question as to the number of readings necessary for 60-cycle calibration by the sphere gap is a very pertinent one. For the data in this paper from 10 to 20 readings were taken for each sphere gap spacing. Ten readings should be sufficient if the voltage is brought up slowly just previous to arcover. "Strays" that depart widely from the mean should be disregarded since it is felt that they are not a measure of the average sparkover voltage. Some strays can be traced to too rapid an application of voltage; others, to sudden air currents. If as many as 20 or 25 per cent of the total readings are strays, usually some condition exists that should be corrected.

I have never encountered the condition

where the first few sparkovers were low, as brought up by Dr. Lusignan, except when the spheres were dirty or wet. Often, when the laboratory has been operating at high humidities, condensation forms drops of water on the sphere arcing surface. At times a few sparkovers will remove these beads of moisture that cause local concentration of voltage. A similar effect is sometimes produced by dust particles. Usually if the spheres are actually dirty, however, successive sparkovers will not clean them. Another cause of low initial sparkovers is the residue of the metal polish used to clean the spheres.

I agree with Dr. Lusignan that it would be of great advantage to have some method for determining when the sphere surfaces are adequately cleaned.

The lack of agreement on voltage measurement between the various sizes of spheres found by Dr. Lusignan has undoubtedly been the cause of a certain amount of dissatisfaction in the use of sphere gaps. The method used in my paper for making impulse calibrations should eliminate the possibility of disagreement among different sizes of sphere gaps, since each size is calibrated by comparison with another size.

## Cross Current of a 5-Arm Network

**Discussion and author's closure of a paper by A. C. Seletzky and J. R. Anderson published in the June 1934 issue, p. 1004–9, and presented for oral discussion at the instruments and measurements session of the summer convention, Hot Springs, Va., June 29, 1934.**

**I. M. Stein** (Leeds and Northrup Co., Philadelphia, Pa.): Both this paper and the companion paper, dealing with cross potential of a 4-arm network, are very commendable contributions to the art of electrical measurement, but I am somewhat disappointed that the authors did not see fit to include a specific practical example of the actual application of the method. While it is true that the introduction to the earlier article refers to practical applications in very general terms, the practical example discussed in detail in the present paper is not really a practical example of the application of the method, but is merely a sample calculation in accordance with the method. It seems to me that the most important practical application of the method would occur in connection with that type of impedance bridge measurement in which the reading is obtained not by balancing the bridge, but by reading the deflection of an instrument connected so as to carry the cross current. It is not clear that the method would have practical application in connection with impedance bridges in which the reading is obtained by balancing the bridge either manually or automatically, particularly as the method is not applicable to many of the problems encountered in practice. The limitations are clearly stated in the paper. Of course, it is well known that even when operating a bridge in the balanced condition, the simple equations representing such balanced conditions are not sufficient because these give no idea of the magnitude and phase of the cross current resulting from an unbalance, and it is necessary to know both the magnitude and phase of the cross current in order to properly select and adjust the detecting circuit. However, there are several fairly simple methods for calculating the magnitude and phase of the cross current for a particular unbalance, and these are perfectly general in their application, being applicable to cases where more than one arm is varied to effect a balance and also to those cases in which the arms are varied in a manner outside of the limitations as stated in the paper. In general, these methods consist in first determining from the simple equation for the balanced condition the value of a particular variable to give this condition, and then determining from the general equation for the cross current the magnitude and phase of the cross current for a specific value of the particular variable, which differs from the value of that variable for the balanced condition by the minimum deviation that it is desired to detect in the measurement. If the complex notation is used, the 2 components of the cross current are easily determined.

At the present time I can see the opportunity for the immediate application of the method in connection with the one practical application which I have mentioned and, of course, the future may disclose some important practical applications in connection with calculations pertaining to bridges operated in the balanced condition.

The only other comment is one which I believe may be helpful to others who may wish to study the papers carefully. In the present paper, the statement is made "the locus of the cross current is a circle" and a similar statement appears in the earlier paper with regard to potential. Also the diagrams in both papers show complete circles. This statement is somewhat misleading. I think it would be better to say "the locus of the cross current lies on a circle" because, in most cases, the locus is really only a small part of a circle.

**A. C. Seletzky** (Case School of Applied Science, Cleveland, Ohio): In the preceding paper (Electrical Engineering, v. 52, no. 12, December 1933, p. 861–7) which treated the variation of cross potential, the network employed for the numerical example was chosen, not as an illustration of any particular type of bridge, but as a simple network which would serve to illustrate the use of circular loci for both fixed and variable frequency of applied voltage. Fortunately, from the standpoint of computation, the loci for a goodly number of bridge circuits follow circles at variable frequency with fixed arms. However, it was desired to use a network in which the cross potential at variable frequency would follow the sum of 2 circles; and it was for this reason that the circuit in question was employed. When it came to the question of selecting a network to illustrate the application to cross currents, the authors considered it advisable, for the sake of continuity, to use the same circuit. Whether or not the network employed is a "practical example" or a "sample calculation" is secondary to the consideration of the employment of a simple circuit to demonstrate the numerical work entailed in the determination of the loci. If the reader comprehends the application of circular loci after studying the network used in the present paper, the authors consider that the "practical example" or "sample calculation" has served its purpose.

In regard to the question of what is the most important practical application of circular loci, the authors prefer to rest with the statement that the method presented is one which gives the locus of cross current when the variable, be it frequency or impedance element, ranges from zero to infinity. Whether or not the method is the simplest available for particular conditions of unbalance depends upon how much information is desired. Doctor Kouwenhoven, in his discussion of the preceding paper (Electrical Engineering, v. 53, no. 3, March 1934, p. 478) considered the advantages of circular loci to determine the orthogonality of variation in cross potential caused by changes of resistance and reactance elements in a bridge arm when close to balance.

## Selsyn Instruments for Position Systems

**Discussion of a paper by T. M. Linville and J. S. Woodward published in the June 1934 issue, p. 953–60, and presented for oral discussion at the instruments and measurements session of the summer convention, Hot Springs, Va., June 29, 1934.**

Paul MacGahan: See discussion below.

## A Telemeter With Pilot Coil Transmitter

**Discussion and author's closure of a paper by L. J. Lunas and H. L. Bernarde published in the June 1934 issue, p. 974–6, and presented for oral discussion at the instruments and measurements session of the summer convention, Hot Springs, Va., June 29, 1934.**

**Paul MacGahan** (Westinghouse Elec. and Mfg. Co., Newark, N. J.): The complete data on the characteristics of the telemeter described in the paper by Lunas and Bernarde will be found in one of the current-type telemeter columns listed in the report of the joint committee on telemeters, a revised edition of which report is practically finished at this time. This telemeter replaces the vacuum tube telemeter which was listed in the original report of this committee and gives quicker response. A speed of response equal to that of ordinary indicating instruments is being demanded by many operating engineers for indications in telemeter systems. The speed obtainable is shown well in the oscillograph slide shown by Mr. Lunas, made since the original paper was published.

In addition, the report containing the column for the high rate impulse-type telemeter includes the data on an entirely new form of such telemeter, a paper on which was planned but not completed in

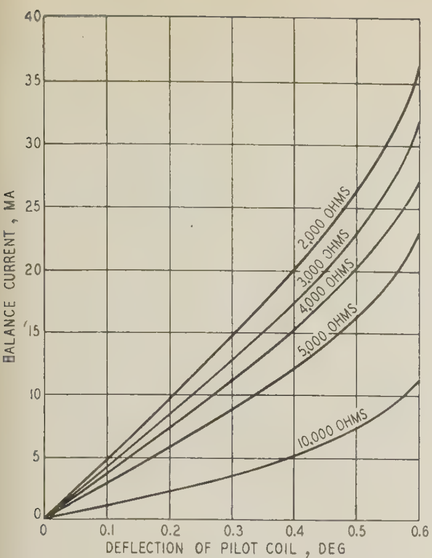



**Fig. 1. Current-deflection characteristics of pilotel telemeter for various line resistances**

time for presentation at this session. This impulse telemeter, however, is quite fully described in the June 1934 issue of the *Electric Journal.* The novel feature is a condenser reservoir device at the receiving end to store energy of the impulses and deliver them at a constant voltage as a steady current to the receiving instruments.

The study of the report may possibly bring up the thought that there is a needless number of different principles of operation used for telemeters and too many varieties in use. This, however, is due to the very great differences in requirements of local conditions, distance and character of available transmission channels, and quantity measured, and is, to a large extent, inevitable. The 4 principal types used are the impulse, voltage, current, and position.

The Westinghouse low rate impulse types operate at not over 15 impulses per minute at full load, and are used for integrating work on account of the requirements at the receiving end where ratchet mechanisms are used to drive integrating or demand registers.

The low rate impulse type is not suitable for indicating or graphic receivers because it is difficult to avoid fluctuation of the receiving instruments caused by the slow period impulses, while at the same time making their response to changes in load quick enough.

The high rate impulse system operating at approximately 250 impulses full load per minute is used for indicating or recording receivers. Generally speaking, this system is used where communication channel conditions or extremely long distances prevent the use of the current systems, such as exemplified by the pilot coil transmitter of the paper by Lunas and Bernarde.

The voltage type telemeter is seen at its best in the paper by Mr. Zogbaum which describes an installation in the New York district. It is peculiarly applicable to the local conditions in New York where the problem is largely one of voltage regulation, or of totalization of generator loads which do not vary too fast to allow the thermal converter transmitters and potentiometer receivers to follow correctly. For other system conditions where short-circuit currents are high, or where loads change rapidly, a telemeter having quick response may be preferable, even if less accurate.

The voltages measured are of the order of magnitude of millivolts, and in view of the prevalence of stray potentials, such as trolley return paths in a large city, presumably special care must be taken to use only high grade communication channels such as leased telephone lines.

The position telemeter class is exemplified in the paper by Linville and Woodward.

The authors have covered the theory of the position type instruments in a very valuable manner. The information in the paper is, however, more generally applicable to devices of this general character than indicated in the title and text, which refers to the trade name of "selsyn."

Numerous other trade names for similar apparatus are in effect, such as "autosyn," "synchrotie," etc., and the broad theory so well presented by the authors would seem to apply to all of these.

It should be clear that the salient pole member may be either the rotor or the stator. In some makes preference is indicated for placing the salient poles on the rotor. In the "Synchrotie" make, the designers have preferred to make the rotor smooth and the stator salient, on account of heat radiation condition being more favorable from the stator than from the rotor.

Concerning further the question of nomenclature, it is confusing to have to contend with so many trade names on such devices. The only A.I.E.E. standardization seems to be that adopted in connection with instrument standards, in which telemeters operating on the principle in question are termed "position" types. A similar basis for a standard name for such a system, when not used for telemeters, would seem to be in order.

**M. E. Reagan** (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): From the point of view of the application engineer, the development of the new current balance telemetering equipment by Messrs. Lunas and Bernarde is of more than usual interest.

The current balance type of telemetering, in the past, has been the most used, the most satisfactory, and the simplest. Two major improvements in performance, high speed of response and small line current, make this new development stand out as a major improvement.

The error produced by leakage on the line is usually very small. Open lines are more subject to leakage than the usual telephone cable circuit because of fog, damp weather, and other by-passes on the receiving element such as limbs lying across the lines.

Since this type transmits much less line current than the older types, the transmitting voltage is proportionately less and, therefore, the chances of leakage or error of transmission is reduced. This reduction of transmission losses combined with indicating meter accuracy will make an ideal system.

The equipment also lends itself to mounting attractively on switchboards with switching and protective equipment since its dimensions follow the standardized trend of mounting on 6-in. centers. The appearance is pleasing and harmonizes fully with other established designs.

**L. J. Lunas** (Westinghouse Elec. and Mfg. Co., Newark, N. J.): The discussion by Mr. MacGahan covers all of the telemeter papers read at this convention, and the questions he touches upon in relation to the other papers will doubtless be covered by the closure statements of their authors. The forthcoming report of the telemeter subcommittee will be a very useful document, judging by the extended use made of this committee's previous report.

While it is true that at the present time there seems to be an unnecessary number of varieties under each general type, it is quite likely that with further experience the best methods will become more clearly apparent and the number of varieties will tend to diminish. Thus, for example, instead of 3 Westinghouse current types these may be reduced to one.

The system described by Mr. Zogbaum emphasizes high accuracy where quick response is not essential. The system I have described is intended to give the same speed of response and the same accuracy as obtained in the usual indicating switchboard instruments.

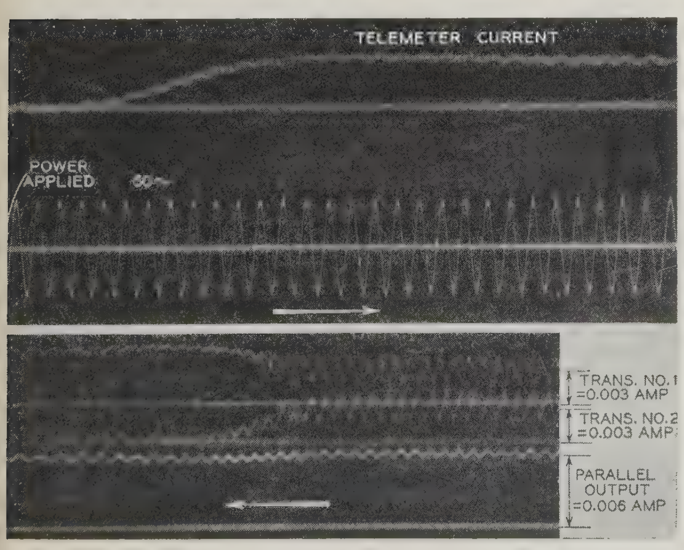



**Fig. 2. Oscillograms of current in pilotel telemeter**

Top trace. Rate of current rise when power is applied

Lower trace. Performance of 2 transmitters in parallel with a sudden rise in the load of one at the same instant that the load suddenly decreases in the other

# News

## Of Institute and Related Activities

# Winter Convention Technical Program Announced

THE technical program for the winter convention of the A.I.E.E. to be held in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 22–25, 1935, will include a wealth of engineering information for the profession. New developments, the latest practice, and recent trends toward standardization in various fields of the industry will be presented and discussed. The convention will convene on a Tuesday and technical sessions will be held both mornings and afternoons for the first 3 days. The evenings will be taken up by social events and arrangements are being made for a smoker Tuesday night, the Edison Medal presentation Wednesday night, and the dinner-dance Thursday night. Friday will be devoted exclusively to inspection trips to various places of interest in and about New York. Further details of these features now being arranged will be announced in the January 1935 issue of ELECTRICAL ENGINEERING.

### Technical Sessions

Twelve technical sessions have been planned to present some of the latest developments in the electrical industry to the membership. Five of these sessions are symposiums which treat the subjects of transformer loading, noise, electronics, and induction motors. The transformer and noise symposiums will give the trends toward standardization in these fields and tell what is being done to bring about the more quiet operation of electrical equipment. Two symposiums on electronics will described the developments and various uses of electronic tubes in the fields of power, measurement, and industrial control. The induction motor symposium will deal with the locked saturation curves, losses, and performance of these machines.

In addition to the foregoing symposiums several other sessions are sure to be of outstanding interest. At the session on education the importance of the social sciences will be stressed by several well-known engineers and executives, and realization by the young engineer of the importance of personality characteristics should be valuable. At the session on general overhead line problems an analysis of lightning phenomena and protective measures against it will be discussed as well as system grounding and the timely subject of d-c power transmission. Another session will treat the subject of illumination. Still others will deal with the subjects of communication, electric welding, electrical machinery, and cables. Thus the program is of broad scope and timely interest which should leave but little to be desired by the average engineer or the specialist.

## Technical Program

The schedule for the 12 sessions and the papers to be presented at each session are given in the following columns. All papers to be presented at the convention are scheduled for publication in ELECTRICAL ENGINEERING prior to the convention. The majority of these papers have already been published in this and preceding issues, beginning with the papers for the illumination session which appeared in the August 1934 issue. All remaining papers which are received in time will be in the January 1935 issue. For the papers which already have been published, reference to the issue and page is given after each title in the list which follows. Members who wish to follow the presentation in detail and discuss the papers are urged to take the necessary issues, or clippings therefrom, to the convention. Excellent discussion should result from the ample opportunity afforded for careful advance study of the papers.

### Tuesday, January 22

**9:00 a.m.—Registration**

**10:00 a.m.—Opening of Convention**

**10:30 a.m.—Electrical Machinery**

HEAT FLOW IN TURBINE GENERATOR ROTORS, C. E. Peck, Westinghouse Electric & Mfg. Co. Oct. issue, p. 1359–65

OUTPUT WAVE SHAPE OF CONTROLLED RECTIFIERS, F. O. Stebbins and C. W. Frick, General Electric Co. Sept. issue, p. 1259–65

TRANSIENTS IN MAGNETIC SYSTEMS, C. F. Wagner, Westinghouse Electric & Mfg. Co. March issue, p. 418–25

**10:30 a.m.—Communication**

WIDE BAND TRANSMISSION OVER COAXIAL LINES, Lloyd Espenschied and M. E. Strieby, Bell Telephone Laboratories, Inc. Oct. issue, p. 1371–80

COAXIAL COMMUNICATION TRANSMISSION LINES, S. A. Schelkunoff, Bell Telephone Laboratories, Inc. Dec. issue, p. 1592–3

BROAD BAND TRANSMISSION OVER BALANCED LINES, A. B. Clark, American Telephone & Telegraph Co. Scheduled for Jan. 1935 issue

**2:00 p.m.—Transformer Symposium**

EFFECT OF OVERLOADS ON TRANSFORMER LIFE, L. C. Nichols, Allis-Chalmers Mfg. Co. Dec. issue, p. 1616–21

OVERLOADING OF POWER TRANSFORMERS, V. M. Montsinger, General Electric Co., and W. M. Dann, Westinghouse Electric & Mfg. Co. Oct. issue, p. 1353–5

IMPULSE AND 60 CYCLE STRENGTH OF AIR, P. L. Bellaschi and W. L. Teague, Westinghouse Electric & Mfg. Co. Dec. issue, p. 1638–45

RECOMMENDED TRANSFORMER STANDARDS, H. V. Putman, Westinghouse Electric & Mfg. Co., and J. E. Clem, General Electric Co. Dec. issue, p. 1594–7

**2:00 p.m.—Education**

ENGINEERING EDUCATION IS MEETING THE CHALLENGE, H. W. Bibber, The Ohio State University. Oct. issue, p. 1357–9

ON THE SCHOOLING OF ENGINEERS, Alex Dow, Detroit Edison Co. Dec. issue, p. 1589–91

ENGINEERING IN THE SOCIAL SCIENCES, J. C. Lincoln, The Lincoln Electric Co. Scheduled for Jan. 1935 issue

CHARACTERISTICS OF A GROUP OF ENGINEERS, Thomas Spooner, Westinghouse Electric & Mfg. Co. Dec. issue, p. 1571–6

### Wednesday, January 23

**10:00 a.m.—General Overhead Line Problems**

LIGHTNING PERFORMANCE OF 220 KV LINES, Lightning and Insulator Subcommittee. Nov. issue, p. 1443–7

OVERVOLTAGES ON TRANSMISSION LINES, C. L. Gilkeson, Edison Electric Institute, and P. A. Jeanne, American Telephone & Telegraph Co. Sept. issue, p. 1301–9

EXPULSION PROTECTIVE GAPS ON 132 KV LINES, Philip Sporn and I. W. Gross, American Gas & Electric Co. Scheduled for Jan. 1935 issue

MULTIPLE LIGHTNING STROKES, K. B. McEachron, General Electric Co. Dec. issue, p. 1633–7

VIBRATION ANALYSIS—TRANSMISSION LINE CONDUCTORS, W. B. Buchanan, Hydro-Electric Power Commission of Ontario. Nov. issue, p. 1478–85

CARRIER CURRENT RELAYS, O. A. Browne, Turners Falls Power & Electric Co., and W. L. Vest, Jr., Western Massachusetts Cos. Scheduled for Jan. 1935 issue

CONSTANT CURRENT D-C POWER TRANSMISSION, B. D. Bedford and F. R. Elder, General Electric Co., and C. H. Willis, Princeton University. Scheduled for Jan. 1935 issue

**10:00 a.m.—Noise Symposium**

MEASUREMENT OF NOISE FROM POWER TRANSFORMERS, A. P. Fugill, The Detroit Edison Co. Dec. issue, p.1603–8

MEASUREMENT OF NOISE FROM SMALL MOTORS, C. G. Veinott, Westinghouse Electric & Mfg. Co. Dec. issue, p. 1624–8

STANDARDIZATION OF NOISE METERS, R. G. McCurdy, American Telephone & Telegraph Co. Scheduled for Jan. 1935 issue

QUIETING A SUBSTATION, E. J. Abbott, University of Michigan. Scheduled for Jan. 1935 issue

THE MEASUREMENT OF NOISE FOR ENGINEERING PURPOSES, B. A. G. Churcher, Metropolitan-Vickers Electrical Co., Ltd. Scheduled for Jan. 1935 issue

**2:00 p.m.—Illumination**

CHARACTERISTICS AND USES OF THE CARBON ARC, W. C. Kalb, National Carbon Co., Inc. Aug. issue, p. 1173–9

LOW PRESSURE GASEOUS DISCHARGE LAMPS, Saul Dushman, General Electric Co. Aug. issue, p. 1204–12; Sept. issue, p. 1283–96

INCANDESCENCE—SOME THEORETICAL ASPECTS, S. G. Hibben, Westinghouse Lamp Co. Aug. issue, p. 1201–4

**2:00 p.m.—Electric Welding**

Transient Voltages in Welding Generators, A. R. Miller, Lehigh University.
Sept. issue, p. 1296–1301

A New Timer for Resistance Welding, R. N. Stoddard, Westinghouse Electric & Mfg. Co.
Oct. issue, p. 1366–70

A High Power Welding Rectifier, Daniel Silverman, Arma Engineering Co., and J. H. Cox, Westinghouse Electric & Mfg. Co.
Oct. issue, p. 1380–3

High Velocity Streams in the Vacuum Arc, E. C. Easton, Harvard University, F. B. Lucas, formerly Lehigh University, and F. Creedy, University of British Columbia. Nov. issue, p. 1454–60

Control of Transients in Welding Generators, F. B. Hornby, General Electric Co.
Dec. issue, p. 1598–1602

## Thursday, January 24

**10:00 a.m.—Electronics Symposium—I**

Theory of Multielectrode Tubes, H. A. Pidgeon, Bell Telephone Laboratories, Inc.
Nov. issue, p. 1485–98

Cathode Ray Tubes and Their Application, J. M. Stinchfield, R.C.A. Radiotron Co., Inc.
Dec. issue, p. 1608–15

Limits to Amplification, J. B. Johnson and F. B. Llewellyn, Bell Telephone Laboratories, Inc.
Nov. issue, p. 1449–54

Electronic Devices in the Field of Measurements, J. W. Horton, Massachusetts Institute of Technology. Scheduled for Jan. 1935 issue

Vacuum Tubes as High Frequency Oscillators, M. J. Kelly and A. L. Samuel, Bell Telephone Laboratories, Inc. Nov. issue, p. 1504–17

**10:00 a.m.—Cables**

Dielectric Properties of Cellulose Paper—Parts I and II, J. B. Whitehead, and E. W. Greenfield, The Johns Hopkins University.
Oct. issue, p. 1389–96; Nov. issue, p. 1498–1503

Resistance and Reactance of 3-Conductor Cables, E. H. Salter, Electrical Testing Laboratories, G. B. Shanklin, General Electric Co., and R. G. Wiseman, Okonite Co. Dec. issue, p. 1581–9

Permissible Neutral Resistance or Reactance for Grounding of Cable Systems, J. E. Clem, General Electric Co.
Scheduled for Jan. 1935 issue

Transient Sheath Voltages on Single-Conductor Cables With Sheath Insulators, Herman Halperin, Commonwealth Edison Co., J. E. Clem, General Electric Co., and K. W. Miller, Utilities Research Commission, Inc.
Scheduled for Jan. 1935 issue

Dielectric Strength of Mineral Oils, F. M. Clark, General Electric Co.
Scheduled for Jan. 1935 issue

**2:00 p.m.—Electronics Symposium—II**

Ratings of Industrial Electronic Tubes, O. W. Pike, General Electric Co., and Dayton Ulrey, Westinghouse Electric & Mfg. Co.
Dec. issue, p. 1577–80

Industrial Electronic Control Applications, F. H. Gulliksen and R. N. Stoddard, Westinghouse Electric & Mfg. Co. Scheduled for Jan. 1935 issue

Industrial Applications of Electron Tubes, D. E. Chambers, General Electric Co.
Scheduled for Jan. 1935 issue

The "Thyratron" Motor, E. F. W. Alexanderson and A. H. Mittag, General Electric Co.
Nov. issue, p. 1517–23

The "Ignitron" Type of Inverter, C. F. Wagner and L. R. Ludwig, Westinghouse Electric & Mfg. Co. Oct. issue, p. 1384–8

**2:00 p.m.—Induction Motor Symposium**

Efficiency Tests of Induction Machines, C. C. Leader and F. D. Phillips, General Electric Co.
Dec. issue, p. 1628–32

Power Losses in Induction Machines, P. M. Narbutovskih, Stanford University.
Nov. issue, p. 1466–71

Induction Motor Locked Saturation Curves, H. M. Norman, Fairbanks, Morse & Co.
Apr. issue, p. 536–41

### Rules on Presenting and Discussing Papers

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes are allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before Feb. 8, 1935. Discussion received after this date will not be accepted.

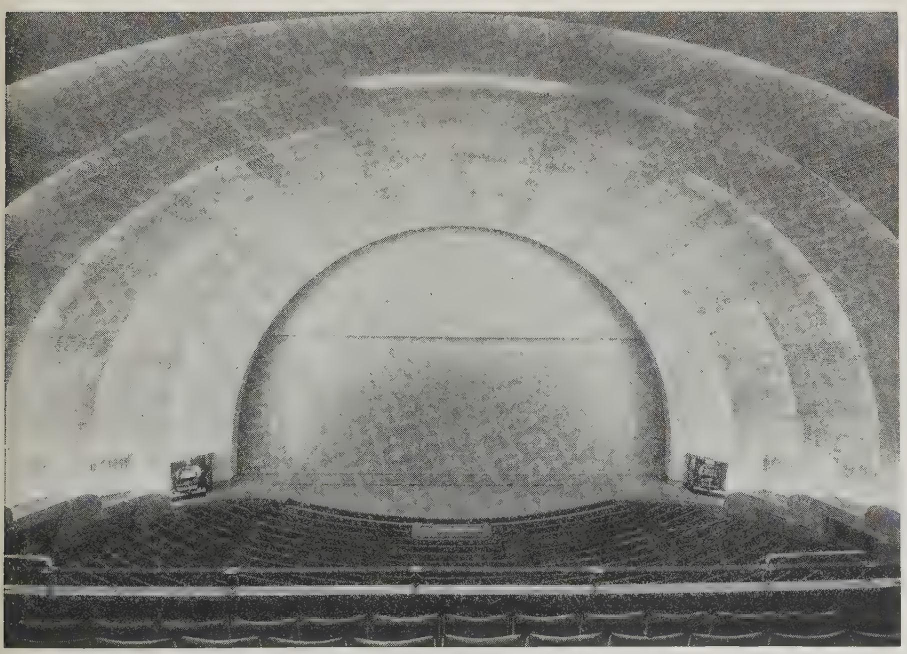
### A Special Hotel Bargain

This year an enterprising hotel within a 15 minute walk from convention headquarters is offering to A.I.E.E. members attending the convention a special "all-expense" rate of $11.20 covering all essential services as follows:

- Room with bath, Jan. 21–24 inclusive
- Meals, including dinners Jan. 21 and 23 and breakfasts Jan. 22–25 inclusive; choice of menus
- Tips for all dining room service, and to bellmen for room service upon arrival

For those wishing to arrive after breakfast Jan. 22, a special rate will be made upon application. Reservations are being held for only 100, and these will be assigned in the order requested.

Those interested should write at once to National Secretary Henline for descriptive booklet and full information. In all other cases, hotel reservations should be made directly with the hotels.



International Music Hall, Radio City, in New York, N. Y., is one of the many points of interest which may be visited by those attending the Institute's winter convention, January 22–25, 1935, in New York. The Music Hall seats 6,200 persons, and the proscenium arch of the stage is 60 feet high. In this view the spectacular flooded ceiling bands with concealed 4 color lighting system are shown. In front of the stage is shown the $166,000 console or control board, by means of which the elaborate stage and auditorium lights are operated

**Applied Mechanics Journal to Be Published.** The American Society of Mechanical Engineers has decided to publish in 4 quarterly issues beginning 1935, a *Journal of Applied Mechanics.* The Journal will contain papers on applied mechanics which have been presented before the applied mechanics division of the Society, besides other papers not so presented, reviews of pertinent literature, and notes on important developments.

An editorial board will be appointed consisting of specialists covering the different branches of the field of applied mechanics, i. e., elasticity, plasticity, strength of materials, vibration, aerodynamics, thermodynamics, film lubrication, and electromechanics. The Journal will be sold to nonmembers at $5 per annum.

## John Fritz Medal for 1935 Awarded Late F. J. Sprague

The John Fritz Gold Medal for 1935 was awarded to Dr. Frank Julian Sprague (A'87, M'97, F'12, HM'32, member for life, and past-president) for "distinguished service as inventor and engineer through the application and control of electric power in transportation systems." This medal, the highest distinction bestowed jointly by the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers of the United States for "notable scientific or industrial achievement," was awarded Doctor Sprague unanimously by the John Fritz Medal board of award at its annual meeting October 19, 1934.

The presentation was to have been made with suitable ceremonies at one of the sessions of the A.I.E.E. winter convention to be held January 22–25, 1935. Unfortunately, Doctor Sprague's death occurred early in the morning of October 25, only a few days after the notification was sent to him that the medal had been awarded him.

Doctor Sprague was a pioneer in the application of electricity to street railways, steam railways, and elevators; among his numerous inventions are many relating to electric motors, multiple unit systems of train control and operation, electric street railways and high speed elevators. He had long been active in the Institute, having served as president 1892–93. A brief biographical sketch of Doctor Sprague's career appeared in Electrical Engineering for May 1934, p. 791; an obituary item appears on p. 1685 of this issue.

The John Fritz Gold Medal is awarded not oftener than once a year for notable scientific or industrial achievement without restriction on account of nationality or sex. It is a memorial to the late John Fritz, a leader in the American iron and steel industry, the first medal having been awarded to Mr. Fritz in 1902. Members of the Institute who have received this medal include: Lord Kelvin (William Thomson) (HM'92); Elihu Thomson (A'84, F'13, HM'28, member for life, and past-president); Guglielmo Marconi (HM'17); Ambrose Swasey (HM'28); Herbert Hoover (HM'29); and M. I. Pupin (A'90, F'15, HM'28), member for life, and past-president). Other John Fritz medalists, no longer living, include: George Westinghouse (A'02); Alexander Graham Bell (A'84, M'84), and past-president); Thomas A. Edison (A'84, M'84, HM'28); Edward D. Adams (A'10); Elmer A. Sperry (A'84, M'93, and member for life); and John J. Carty (A'90, F'13, HM'28, member for life, and past-president).

## Middle Eastern District Executive Committee Meets

A meeting of the executive committee of the A.I.E.E. Middle Eastern District (number 2) was held in Pittsburgh, Pa., October 20, 1934.

Those in attendance were:

**Delegates**

R. A. Hudson, chairman, Akron Section
J. H. Lampe, secretary, Baltimore Section
E. J. Jonas, chairman, Cincinnati Section
W. H. LaMond, chairman, Cleveland Section
A. S. Goodrich, chairman, Erie Section
Edgar Bell, secretary, Lehigh Valley Section
C. D. Fawcett, delegate, Philadelphia Section
H. A. P. Langstaff, chairman, Pittsburgh Section
F. J. Vogel, chairman, Sharon Section
G. W. Emery, delegate, Toledo Section
H. G. Dorsey, chairman, Washington Section
A. M. Wilson, vice president, District number 2
G. McC. Porter, counselor, District number 2
L. L. Bosch, secretary, District number 2

**Non-Delegates**

H. H. Henline, national secretary, New York, N. Y.
H. H. Schroeder, secretary, Akron Section
H. T. Killingsworth, secretary, Cleveland Section
C. A. Powel, secretary, Pittsburgh Section
W. I. Albert, member, Pittsburgh Section
W. A. Summer, secretary, Sharon Section
Columbus Section was not represented.

At this meeting, Prof. A. M. Wilson was elected representative from District number 2 on the national nominating committee. W. H. Harrison of Philadelphia, Pa., was unanimously nominated a candidate for the Institute's vice president from District number 2.

The following were elected as members of the District's coördinating committee: H. A. P. Langstaff, W. A. LaMond, H. G. Dorsey, and Edgar Bell. These elected members, together with the vice president, District counselor, and District secretary constitute the District's coördinating committee.

The following were nominated as members of the prize paper committee: Prof. T. B. Owens, Cleveland, Ohio; Prof. H. E. Dyche, Pittsburgh, Pa.; and F. C. Hanker, Pittsburgh, Pa. The election of the committee was, however, deferred until after all papers are submitted for consideration, so that a committee could be selected of which no member would be called upon to review a paper one of his students or co-workers had presented. The date of presenting papers was changed to September 1, so as to put responsibility for presenting papers upon only one group of officers. Vice President Wilson urged each Section to stimulate interest in the presentation of papers for prize consideration.

A motion was passed that a meeting of the Middle Eastern District be held in Akron, Ohio, during 1936.

## North Central District Executive Committee Meets

The annual meeting of the executive committee of the Institute's North Central District number 6, was held at Denver, Colorado, on October 26, 1934.

Those in attendance were:

R. B. Bonney, vice president
T. H. Granfield, chairman, Nebraska Section
R. H. Owen, secretary, Denver Section
N. R. Love, representing G. S. Dring, chairman, Denver Section
W. G. Rubel, District sectretary
Prof. H. S. Rush, Chairman of the District committee on Student activities, was unable to be present.

Mr. Bonney called for nominations for the office of vice president of District number 6, the candidate for this office to be voted for in the election of national officers in 1935. R. H. Fair, of Omaha, a charter member of the Nebraska Section, was unanimously nominated for the office of vice president of District number 6.

Prof. G. H. Sechrist of the University of Wyoming was appointed to be the member of the national nominating committee from this District.

The selection of a District committee on prize awards to act as judges in awarding prizes to the authors of meritorious papers presented at Section or Branch meetings during 1934 was next considered. It was decided that the executive committee would elect one member to serve as chairman of the committee, and request the 2 Sections in the District to each select one member to complete a committee of 3. W. D. Hardaway of Denver was chosen to act as chairman of the committee.

The District conference on student activities was next discussed. At a previous

## Membership—

Mr. Institute Member:

You frequently ask "What do I get for my dues?" We take it that you mean "What am I doing with my dues through my Institute?"

You will find the answer in Electrical Engineering for:

March 1934, page 375–81, by E. B. Meyer
July 1934, page 1039–46, by J. Allen Johnson
November 1934, page 1542–3, by R. H. Tapscott

Your Section membership committee has reprints in convenient booklet form of Mr. Johnson's article. We suggest you use them in a Section meeting. You will be pleased to hear all of the good things you are doing through your Institute.

Chairman National Membership Committee

Branch conference, the Branch counsellors voted to meet in Fargo, North Dakota, at the North Dakota Agricultural College for the 1935 conference. The executive committee heartily approved the holding of the District Branch conference and the secretary was instructed to notify Prof. H. S. Rush, chairman of the committee on Student activities, of the action of the executive committee and request him to proceed with plans for a District conference in 1935.

After considerable discussion of Institute matters, particularly the activities of the section membership committees and program committees, the meeting was adjourned.

## Future AIEE Meetings

**Winter Convention**
New York, N. Y., Jan. 22–25, 1935

**South West District Meeting,**
Oklahoma City, Okla., Apr. 24–26, 1935

**Summer Convention,**
Ithaca, N. Y., June 24–28, 1935

**Pacific Coast Convention,**
Los Angeles vicinity, Fall 1935

**Great Lakes District Meeting,**
Indianapolis—Lafayette Section territory (Date to be determined)

# Announcement of A.I.E.E. Prizes for Technical Papers

AUTHORS who plan to present papers before the Institute during the calendar year 1935, those who have presented papers during 1934, and others who may wish to submit papers for prizes, would do well to bear in mind that such papers are eligible for consideration for Institute prizes. These awards are made each spring for the preceding calendar year, and fall into 2 main classes, national and District prizes.

In accordance with the practice followed during the past 2 years, the board of directors decided to omit the cash awards for papers presented during the calendar year 1934, except that a payment of $25 in cash will accompany each District prize for Branch paper. All certificates will be issued as usual, those for national prizes signed by Institute officers, and those for District prizes signed by the officers of the Districts concerned. In cases of joint authorship, a certificate will be issued to each author.

### National Prizes

The national prizes which may be awarded at the discretion of the committee on award of Institute prizes are as follows:

1. Prizes for best papers in (1) *engineering practice*, (2) *theory and research*, and (3) *public relations and education*.
2. Prize for initial paper.
3. Prize for Branch paper.

The national prize for best paper in each of the 3 classes indicated may be awarded to the author or authors of the best original paper presented at any national, District, or Section meeting of the Institute, provided the author, or at least one of co-workers, is a member of the Institute.

The national prize for initial paper may be awarded to the author or authors of the most worthy paper presented at any national, District, Section, or Branch meeting of the Institute, provided the author or authors have never previously presented a paper which has been accepted by the technical program committee, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The national prize for Branch paper may be awarded to the author or authors of the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Student Branch members.

All papers approved by the technical program committee which are presented at any meeting will be considered by the committee on award for the prizes for best paper and initial paper without being formally offered for competition. All papers other than those presented to the technical program committee must, in order to receive consideration, be submitted in triplicate with a written communication to the national secretary on or before February 15 of the year following the calendar year in which they were presented. This may be done by the author or authors, by an officer of the Institute, or by the executive committees of Sections, or Geographical Districts.

### District Prizes

The following District prizes may be awarded each year in each Geographical District of the Institute:

1. Prize for best paper.
2. Prize for initial paper.
3. Prize for Branch paper.

A District prize may be awarded only to an author who, or to co-authors of whom at least one, is located within the District, and for a paper presented at a meeting held within, or under the auspices of, the District.

The District prize for best paper may be awarded for the best paper presented at a national, District, or Section meeting, provided the author, or at least one of co-authors, is a member of the Institute.

The District prize for initial paper may be awarded for the best paper presented at a national, District, Section, or Branch meeting, provided the author or authors have never before presented a paper before a national, District, or Section meeting of the Institute, and the author, or at least one of co-authors, is a member of the Institute, or a Graduate student enrolled as a Student of the Institute.

The District prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, the author or authors of which are Student Branch members.

All papers to be considered in competition for District prizes must be submitted in duplicate by the authors or by the officers of the Branch, Section, or District concerned to the District committee on awards on or before January 10 of the year following the calendar year in which the papers have been presented.

Copies of a pamphlet entitled "National and District Prizes" may be secured, without charge, upon application to Institute headquarters.

**A.S.T.M. Elects New Officers.** Hermann Von Schrenk, consulting timber engineer, St. Louis, Mo., and senior vice president of the American Society for Testing Materials, was elected by its executive committee to the office of president on October 9, 1934, to fill the vacancy caused by the death of W. H. Bassett who died July 21, 1934 (see ELECTRICAL ENGINEERING for Sept. 1934, page 1326). The vacancy created by Doctor Von Schrenk's election was filled by the appointment of H. S. VASSAR (A'06, M'18) as senior vice president, Mr. Vassar having been elected a vice president last June; he is laboratory engineer for the Public Service Electric and Gas Company, Newark, N. J. A. C. Fielder, chief engineer, Experiment Stations Division, U.S. Bureau of Mines, Washington, D. C., has been elected junior vice president.

# "Science Series" Will Be Reprinted

In response to the widespread demand that resulted from the preliminary announcement made in the preceding issue of ELECTRICAL ENGINEERING, the special "Science Series for Engineers" that has been appearing in the pages of ELECTRICAL ENGINEERING during the past year will be reprinted and made available for distribution approximately February 1, 1935. By the time of its conclusion in the January 1935 issue of ELECTRICAL ENGINEERING, this series will have consisted of 13 articles, each on one of the more important fields of present day science, and each prepared by an authority in the field discussed, and each fully up to date as of the month of publication.

The booklet will comprise between 80 and 90 pages ($8^1/_2 \times 11$ inches) substantially bound and covered. Such a booklet should be of particular value to the practicing engineer, the recent graduate, the engineering student, and the future study of engineering subjects, as it will afford an authoritative digest of important current developments in several fields of science closely related to electrical engineering. Although most of the advance requests recorded to date have come as individual orders, several inquiries for quantity lots

have been received from colleges and universities where it is contemplated that the reprint will be required reading for technical students.

Although the issuance of the reprint is assured, the number printed will be determined upon the basis of the total number of orders that have been filed with the A.I.E.E. editorial department by Monday, January 7, 1935. For convenience, an order blank appears in the advertising section of this issue.

# American Engineering Council—And Its Relation to the Institute

SUPPLEMENTING other articles recently appearing in ELECTRICAL ENGINEERING which serve to acquaint the membership of the Institute with its activities, interests, and inner workings (such as the 3 articles referred to in the "membership" item on page 1664 of this issue) the following comments on American Engineering Council and the interrelation between Council and the A.I.E.E. are offered. This article was prepared by Dr. J. B. Whitehead (A'00, M'08, F'12, and Life Member) junior past-president of the Institute:

### American Engineering Council

American Engineering Council was founded in 1920 with the object "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions." It includes in its membership about 20 national, state, and local engineering societies. Its headquarters are in Washington, D. C., principally because one of its recognized duties is the offering of advice and assistance in the formulation of legislation involving engineering enterprise, and further because of the opportunities thereby offered for contact with various departments of the National Government which are commonly engaged in undertakings involving engineering advice and services. Two distinctly definite purposes are in view in these relationships. The first is that the engineering profession may be advised promptly of all legislation which may possibly affect the profession as a whole as well as its individual members, and second that the profession may make readily available to the Government, not only professional advice when such is desired, but also may have a rapid medium of exchange of information as to where engineers are needed and where suitable competent engineers may be obtained.

### Desirability of a Central Organization

There are approximately 150,000 engineers of recognized professional standing in the United States; if those in subordinate technical positions be included, the number is more nearly 225,000. It is a remarkable and very unfortunate fact that this great body of professional men, having many interests and ideals in common, have not yet set up a central organization representative of the engineering profession as a whole, which is qualified and authorized to speak for it on matters of public interest.

The reason for this condition is that the 4 great national societies of civil, mechanical, mining and metallurgical, and electrical engineers were founded in an earlier period, in which the relationship of engineering undertakings to civic and national affairs was less important. Each of them has grown independently and in its own field, because the special aims of each are the advancement of the respective technical arts, and the elevation within those arts of professional standards. Nowhere apparently within the vision of the founders of the national societies, nor in their constitutions, is there evidence of a belief that questions arising in a future complexity of the relations of industrial enterprise to civic and national economy and government, should be directly attacked independently by the respective engineering societies.

The question is no new one. Throughout the years, these 4 founder societies have frequently coöperated with each other in matters of common concern, particularly in those involving material interests, through joint committees or other bodies with greater authority, such as United Engineering Trustees, American Standards Association, and others. These bodies however, exist for the specific purposes, such as the operation of the Engineering Societies Building, the Engineering Societies Library, and other matters of similar nature. They are not empowered to speak for the profession as a whole on matters of either professional or public interest or import. However, the founder societies, together with others throughout the country, have set up one joint agency which, through its original charter and subsequent development, in some measure meets the need of a single agency which concerns itself with the interests of the profession as a whole, and provides at least a forum and a medium for the discussion of the manifold inter-relationships in modern life among the engineering profession, the individual engineer, and the public welfare. The name of this body is American Engineering Council.

### Other Opportunities for Council

Thus American Engineering Council has many other opportunities and duties

# A "Million Dollar Car"

ABOUT 5 years ago a fund was made available through the efforts of the Electric Railway Presidents' Conference Committee for the development of an improved type of street car. The result of the research work, carried on under the direction of Dr. C. F. Hirshfeld (A'05) of Detroit, Mich., is the car pictured here, which cost upward of $1,000,000 to build. This car, one of 4 designed as the outgrowth of the research work of the committee, incorporates many innovations in design. The car is practically noiseless, due partly to the resilient type of wheel obtained by the use of steel parts interlocked with rubber. Trucks are specially designed, rubber springs being used. In the construction of the body, a newly developed alloy corrosion-resisting steel known as "cor-ten" has been used, and welding is used extensively. The weight of the complete car is approximately 31,000 pounds, and it seats 50 passengers. Forced ventilation and indirect illumination are used. Among the unusual features of the car are its extremely rapid but smooth starting and stopping, it being claimed that the car can get under way 10 to 15 per cent faster than the most modern type of automobile. This is particularly important in maintaining high schedule speeds with frequent stops in congested traffic. The committee under which it was developed is composed of the leading executives of some 25 of the larger street railways in the United States. A number of the larger manufacturers of cars and equipment coöperated with the committee.

beyond those outlined in the opening paragraph above. It is within its proper province to develop discussion of any matter of public interest involving engineering services. Its annual reports, abstracts from which are published from time to time in ELECTRICAL ENGINEERING enumerate many instances of this type of activity. The wide range taken by these discussions is indicated by the list of special committees of of the Assembly, of which there are 12 or more active at present. Among these may be mentioned, as illustrating the scope of the Council's interests, the committees on administration of public works, communications, engineers water power policy, flood control, patents, relation of consumption, production and distribution, and the like. During the past year a number of questions were referred to the Institute, the proper study of which would involve far more time than could be given to them under the Institute's voluntary committee system, and which in general did not fall within the scope of the Institute's normal types of activity. Three such instances were: the effect of the N.R.A. codes on the profession, employment conditions for engineers imposed by the federal government, federal public works policies involving governmental competition. Such questions, always important not only to the electrical engineer, but to the profession as a whole, are frequently arising from both within and without the Institute. They are commonly referred to American Engineering Council. Council has always attacked such questions effectively. In many cases satisfactory action or answer have resulted. In others of more permanent nature, the interests of engineers are being constantly protected through the furnishing of information, or the dignified advocacy of the rights of engineers as based on the high principles of the profession.

### Council Could Be Made More Valuable to the Institute

From the foregoing it will be seen that in 2 of its functions American Engineering Council should appeal especially to members of the Institute. First it is the only existing agency properly authorized for joint discussion and utterance on matters of interest to the engineering profession as a whole. With comparatively slight modification in organization, Council could probably be converted into the ideal body for this purpose. The second effective service being rendered by Council to members of the Institute is in its concern for the material and economic welfare of the individual engineer. This is one of its normal functions. Instances of activities of this type have been indicated above. Questions involving the welfare of the individual electrical engineer also frequently arise both within and without the Institute. They are referred to American Engineering Council as one of its prime concerns. For these and other reasons the board of directors of the Institute has indicated by repeated action that it believes that American Engineering Council should be supported and developed. The method for this development is through the joint and proportionate coöperation of the various engineering societies of the country, with the enthusiastic support of their respective memberships. At present, the annual appropriations of the supporting founder societies to American Engineering Council are only about $^1/_3$ their average value over a number of years up to 1931. Desirable activities for American Engineering Council are correspondingly limited. The present appropriations should be increased if the full value of the Council is to be realized.

## A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition.

Instead of offering the entire list to the readers of ELECTRICAL ENGINEERING at one time, it is felt that its purpose will be served better if only a few books are mentioned each month. Accordingly, the suggested books which fall under the classification of "Natural Science" are presented herewith; books on other subjects, such as philosophy, economics, sociology, psychology, business and industrial management, literature, history, biography, travel, fine arts, and a general list are scheduled for publication in subsequent issues.

The list has been prepared on the basis of a generally accepted classification. It includes more than 100 titles, and it is suggested that over a period of about 4 years a minimum of 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

### Natural Science

**Concerning the Nature of Things, William Bragg.** Harper, 1925. A simple account, with many photographs, of the properties of atoms, and of the nature of gases, liquids, and crystals. Author is a pioneer in X ray work.

**History of Science and Its Relation to Philosophy and Religion, W. C. Dampier-Wetham.** Macmillan, 1929. Evolution of scientific thought and research from dawn of history in Babylonia and Egypt, through the speculations of Greece, and past the blind alleys of the Middle Ages to the present.

**Origin of Species, Charles Darwin.** Appleton, 1900. The preservation of favored races in the struggle for life. Contains additions and corrections from the sixth and last English edition. Is not speculation, but evidence of what actually is.

**New Conceptions of Matter, C. G. Darwin.** Macmillan, 1931. Originally a series of lectures at Lowell Institute, Boston. Author is Tait Professor at University of Edinburgh. Book presents the broad features of the new theoretical physics in nontechnical terms.

**The Nature of the Physical World, A. S. Eddington.** Macmillan, 1928. Takes up both relativity and the quantum theory and traces the effect of modern concepts on free will and determinism.

**Philosophical Basis of Biology, J. S. Haldane.** Doubleday, Doran, 1931. Object of this volume is to present the theoretical basis of the nature of life which "biological observation seems to force upon us." Lectures were given under Donellen Foundation at Trinity College, Dublin.

**Mysterious Universe, Sir James Jeans.** Macmillan, 1932. A discussion for the layman of our relation to the universe. Man's increased knowledge has resulted in a new formulation of this problem which has interested philosophers for thousands of years. Presentation is simple and lucid and, of course, authoritative.

**Human Life as the Biologist Sees It, Vernon Kellogg.** Henry Holt, 1922. For the layman. Interprets in simple language what science teaches about mankind in its relationship to origins, heredity, everyday life, death, the soul, and the future.

**The Living Past, J. C. Merriam.** Scribner, 1930. A study of evolution from plant and animal life as indicated in footprints, bones, leaf imprints, skeletons, and other remains found in various parts of the country.

**Grammar of Science, Karl Pearson.** (London) A. & C. Black, second edition, 1900. Exposition of the meaning of scientific law. Interesting questions and analogies. Much destructive criticism of earlier scientists. This latest edition contains 2 new chapters: one on contingencies and correlations, and another on modern physical ideas.

**What Industry Owes to Chemical Science, R. B. Pilcher and Frank Butler-Jones.** Van Nostrand, 1931. A fine résumé of advances made in metallurgy and manufacture and various commodities and the application of scientific research. Very readable and most compact and a convenient history of industrial chemistry.

**Man and Metals, T. A. Rickard.** McGraw-Hill, Whittlesey House, 1932. A history of mining in relation to the development of civilization from prehistoric times. The author is an authority and the book full of information.

**Flights From Chaos, Harlow Shapley.** McGraw-Hill, 1930. The reader will find it valuable whether he knows little or much about astronomy. A good stretching exercise for the imagination.

**Modern Science, Sir J. A. Thomson.** Putnam, 1930. The author discusses this question: Will the teachings of astronomy and science change our outlook on the universe as a whole, and the meaning of human life? Book is valuable as a means of provoking thought.

**Geography, H. W. Van Loon.** Simon and Schuster, 1932. Popular geography, emphasizing the human interest side of the world we live in. Discusses why we live where we do, where we came from, and what we are doing.

**T.V.A. Orders Gas-Electric Locomotives.** On what is reported to be their most important engineering project to date, the Tennessee Valley Authority is using 4 10-ton Plymouth-Westinghouse gas-electric locomotives to haul the nearly 1,000,000 cubic yards of concrete which will be required for the Norris Dam. The locomotives haul Insley concrete cars from the concrete mixing plant and operate the

motors to tilt the 4 cubic yard skips into the hand dump concrete buckets on the cableways spanning the valley and covering the entire dam, spillway, and power house area. The gas-electric generators on the locomotives supply the power for all of these operations to the buckets at the dam site. These 12 foot long locomotives are powerful and fast. The starting tractive effort with 25 per cent adhesion is 5,000 pounds; continuous tractive effort is 1,650 pounds. With a maximum safe speed of 23 miles per hour, the locomotive has a free running speed of 15 miles per hour and a 10 mile per hour speed when operating at the continuous tractive effort rating.

# Services of Engineering Societies Library Available

THERE is a large group of engineers who cannot visit the Engineering Societies library because of distance or lack of time. Therefore the library maintains a "service bureau" to make available to each engineer the information he needs. This bureau searches for information on all phases of engineering, suggests books or magazine articles, prepares bibliographies tells what is in the bibliographies by means of abstracts, supplies photoprints of material in the library, and makes foreign language publications usable by providing accurate translations.

The services of the bureau range from suggesting a book or 1 or 2 articles on a given subject to the preparation of exhaustive bibliographies for use in engineering projects or in patent litigation. A loan collection of modern American engineering books is also maintained from the convenience of members of the 4 national societies of civil, mechanical, mining and metallurgical, and electrical engineers, and contributing societies. The investigations of the bureau are not limited to the extensive resources of the Engineering Societies Library. Engineering Societies Library searchers have access to all libraries in New York City and use them to answer questions in fields more or less related to engineering.

More than $^{1}/_{3}$ of the total number of people using the library each year cannot visit it in person, and as a part of the Engineering Societies Library, the service bureau has served engineers in every state of the United States as well as in more than 50 foreign countries.

### Bibliographies

When bibliographies are furnished by the service bureau the mere possession of a list of books and articles may not solve the engineer's problem. He will probably need the information to be found in literature, rather than a mere list. Thus it has been necessary to extend the work of the service bureau so as to offer approximately the equivalent of a visit to the library. When bibliographies are compiled a note is appended to each article explaining what it is about, so that the recipient of the bibliography can tell whether he needs to read a given article as a whole, in part, or not at all. When he has determined what articles he should read, if he cannot obtain them at a local library, he may send a list of them to the Engineering Societies Library to have photostatic copies made. The library is equipped to supply photoprints of all material on file. But even the possession of an exact copy of an article may be insufficient if the article is in a foreign language. In such cases the service bureau supplies exact, technically accurate translations.

It is to be noted that the service bureau has on file more than 4,000 bibliographies already made up on special engineering subjects. Any of these may be procured by paying a moderate copying charge. As an example of the type of material contained in these lists, some of the bibliographies on various aspects of electrical engineering are listed in table I.

Some of the other electrical engineering subjects covered or partially covered by bibliographies already compiled and in the files are: Accelerator tubes, arc furnaces, arc rectifiers, arc welding, arcing rings, artificial electric lines, batteries, copper wire, dielectric constants, electric arcs, electric automobiles, electric boilers, electric cables, electric cells, electric condensers, electric conductivity, electric conductors, electric conduits, electric cooking, electric distribution, electric drives, electric elevators, electric furnaces, electric galvanizing, electric generators, electric heating, electric lamps, electric lines, electric locomotives, electric machinery, electric meters, electric

**Table I—Examples of Type of Subjects on Which Bibliographies Are Already on File**

| Search Number | Number of References | Cost of Copy | Subject or title of list | Dates Covered |
|---|---|---|---|---|
| 3874 | 23 | $1.50 | Power factor | 1913–1923 |
| 4032 | 133 | 5.00 | Muscle Shoals | 1916–1925 |
| 4566 | 522 | 15.00 | Interconnected networks (not annotated) | 1918–1930 |
| 4380 | 15 | 1.25 | Automatically controlled hydroelectric power stations | 1923–1927 |
| 4556 | 40 | 1.75 | Electric power plants | 1927–1930 |
| 3921 | 76 | 5.00 | Ventilation and temperature rise in electric machinery | 1901–1924 |
| 3707 | 452 | 19.50 | Power losses in electric machinery | 1885–1922 |
| 4527 | 13 | 1.00 | Prevention of frosting in relays, motors, etc. | 1904–1927 |
| 4019 | 26 | 2.00 | Third brush generator | 1913–1920 |
| 3295 | 16 | 1.50 | Designing and testing fractional horsepower motors | 1901–1918 |
| 4525 | 18 | 1.25 | Single-phase synchronous motors | 1913–1928 |
| 4071 | 32 | 2.25 | Magnetic leakage in induction motors | 1903–1925 |
| 4638 | 7 | 0.50 | Shaded pole a-c induction motors | 1898–1931 |
| 4223 | 133 | 9.50 | Electrolytic rectifiers | 1866–1926 |
| 4263 | 8 | 0.75 | Wind pressure on transmission lines | 1920–1925 |
| 4261 | 11 | 0.75 | Ice on transmission lines | 1917–1926 |
| 3650 | 66 | 5.00 | Rubber insulated wire | 1895–1922 |
| 4391 | 13 | 1.25 | Corrosion of underground lead cable | 1907–1928 |
| 4358 | 109 | 7.00 | Underground transmission and distribution | 1922–1927 |
| 3941 | 36 | 2.25 | Heating of buried electric cables | 1900–1923 |
| 3559 | 21 | 1.50 | Copper conductors | 1911–1921 |
| 3772 | 358 | 11.00 | Iron and steel electric wire and cables | 1838–1924 |
| 4444 | 21 | 1.25 | Impulse breakdown tests on dielectrics | 1900–1928 |
| 3259 | 9 | 0.75 | Sludging test for transformer oil | 1911–1920 |
| 4453 | 7 | 0.50 | Oxygen in insulating oils | 1913–1928 |
| 2755 | 48 | 3.50 | Materials for molded insulators, excluding porcelain | 1910–1919 |
| 3054 | 7 | 0.75 | Suspension insulators | 1912–1920 |
| 4568 | 28 | 1.25 | Transmission line masts (not annotated) | 1925–1930 |
| 3638 | 10 | 0.75 | Stresses in steel towers for transmission lines | 1910–1921 |
| 3867 | 61 | 4.00 | Steel towers for transmission lines | 1891–1912 |
| 2126 | 26 | 1.75 | D-c vs. a-c for urban distribution | 1896–1918 |
| 4648 | 49 | 2.50 | High voltage substations | 1927–1931 |
| 4477 | 6 | 0.50 | Storage batteries in substations | 1926–1928 |
| 2821 | 18 | 1.50 | Rheostats | 1912–1918 |
| 4504 | 76 | 3.50 | Lightning arresters | 1924–1929 |
| 4344 | 13 | 1.00 | Arcing rings | 1921–1927 |
| 4180 | 12 | 1.00 | Ground wires for overhead transmission lines | 1913–1925 |
| 3837 | 14 | 1.00 | Braun tube oscillograph | 1897–1923 |
| 4015 | 15 | 1.00 | Design and construction of solenoid type magnets | 1911–1924 |
| 4637 | 54 | 3.50 | Lifting magnets (American literature only) | 1832–1929 |
| 4247 | 31 | 2.00 | Electrolytic condensers | 1908-1931 |
| 4595 | 25 | 1.50 | Neon tubes | 1927–1931 |
| 3589 | 156 | 5.00 | Electrification of railroads (not annotated) | 1913–1921 |
| 4326 | 43 | 3.00 | Diesel-electric locomotives | 1927 |
| 3324 | 69 | 6.00 | Advantages of electric drive in industry | 1916–1920 |
| 3155 | 31 | 2.50 | Gas batteries | 1839–1913 |
| 2844 | 10 | 1.00 | Manufacture of storage batteries | 1902–1917 |
| 3418 | 38 | 2.00 | Design and manufacture of lead storage batteries | 1911–1921 |
| 3865 | 13 | 0.75 | Electrochemical and electrothermal processes | 1910–1923 |
| 3710 | 5 | 0.50 | A-c electrolysis | 1907–1921 |
| 1343 | 15 | 1.00 | Electricity direct from heat | 1894–1904 |
| 4400 | 6 | 0.75 | Thermocouple electric generators | 1910–1925 |
| 2907 | 64 | 4.00 | Electric heating and cooking | 1916–1920 |
| 2957 | 33 | 2.00 | Electric resistance furnaces | 1914–1920 |
| 4037 | 49 | 3.50 | Selenium cells | 1903–1916 |
| 4651 | 8 | 0.75 | X ray transmission and reception | 1923–1930 |
| 2116 | 55 | 2.50 | Poulsen's telegraphone | 1899–1908 |
| 2758 | 91 | 3.50 | Inductive interference between power and telephone circuits | 1887–1919 |

motors, electric plowing, electric power plants, electric prospecting, electric railways, electric rates, electric shock, electric trucks, electric welding, electric wires and wiring, electricity, electricity from heat, electrification of railways, electrodeposition, electrodes, electrolysis, electrolytic condensers, electromagnets, electron tubes, foundations for electric machinery, frequency changing, frosting of electric machinery, glow lamps, grounds, high frequency circuits, high voltage transmission, hydroelectric plants, hydroelectric power, incandescent lamps, induction motors, inductive interference, insulating materials, insulating materials, insulators, interconnection, interference, lamp sockets, lamps, magnetic clutches, magnetic permeability, magnetic separation, magnetic testing, magnetism, magnets, mica insulation, motors, neon tubes, radio, railroad signals, rectifiers, relays, remote control, resistance, resistivity, resistors, rheostats, rotary converters, selenium cells, substations, telegraphy, telephony, Thury electric transmission, transformers, transmission lines, ventilation of electric machinery, watt-hour meters, wave filters, welding, wire, wired wireless, X ray testing, X rays.

Any of these bibliographies may be brought up to date or extended as far back as may be required. Estimates for such work will be furnished by the library on request. If a problem is not covered by one of the bibliographies on file, the service bureau will gladly try to find the information needed, and if that cannot be done within the time available for free work it will advise the member of the need for a search and its probable cost.

The resources of the Engineering Societies Library are thus made available to engineers everywhere. All services are rendered at cost. For information communicate with the Engineering Societies Library, 29 West 39 Street, New York, N. Y.

## A.S.T.M. Reports on Electrical Research Activities

IN A supplement to the A.S.T.M. *Bulletin* for October 1934, there were reviewed in brief 51 A.S.T.M. committee projects "initiated primarily to extend and amplify the knowledge of the properties of materials," and 63 committee projects "devoted to methods of testing in connection with which there are conducted investigations . . . . . that may lead to the preparation of standard test methods. . . . . ." Among the latter 63 items were the following 10 under the jurisdiction of A.S.T.M. committee *D*-9 which are reflected here because of their probable interest value to electrical engineers in particular: (these summaries include "information not otherwise generally available except after laborious reference to reports of 60 research, joint, and standing committees.")

*Tests of Insulating Varnishes.* Investigation and development of the following methods for varnish films: hardness and oil resistance; acid and alkali resistance; and insulation resistance. See preprint, 1934 report of committee *D*-9.

*Tests of Saturant Varnishes.* Studies of such properties of saturant varnishes as impregnation, internal drying, bonding strength, and dielectric strength when the varnish is used as an impregnating medium in cotton fabrics. Work recently undertaken; not yet reported upon.

*Tests of Molded Insulating Materials.* Investigation of methods of measuring impact fatigue of molded phenol plastics, and studies of dimensional tolerances suitable for phenol plastic impact test specimens and of the effect of moisture content on impact and transverse strength of phenol plastic test specimens. Investigation of the effect of the type of mold used on the physical strengths of plastic molded test specimens. Also tests for density and particle size of molding powders and plasticity and cure tests. Improvements in impact specimens prepared; also methods of testing molding powders used in manufacturing molded electrical insulators developed, see preprint, 1934 report of committee *D*-9.

*Tests of Insulating Papers and Fabrics.* Investigation and development of methods and apparatus for testing insulating papers, as follows: Procedure for measuring thickness; instruments for determining tearing strength and folding endurance; tests for moisture in impregnated cable paper; acidity tests; air resistance of insulating paper and effect of humidity on dielectric strength of varnished cambric. Methods for thickness and folding endurance developed also specifications and tests for varnished cloth tape and flexible tubing, see preprint, 1934 report of committee *D*-9.

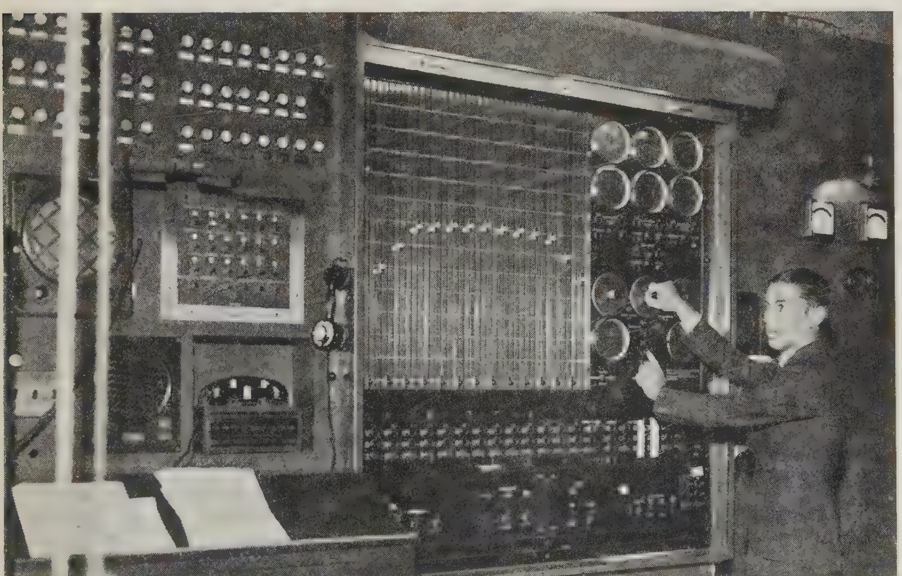
*Tests of Insulating Sheets, Tubes and Rods.* The following studies of laminated sheet insulating materials are being conducted: Method for determining compressibility as a function of time; methods of measuring the modulus of elasticity in compression; the effect of temperature variations on water absorption; effect of humidity on dielectric strength and on flexural strength; impact fatigue tests, arc resistance, hardness tests, punching quality, and insulation resistance tests; also methods of test for flammability and heat resistance. Indentation hardness test using Rockwell tester developed. For current progress, see preprint, 1934 report of committee *D*-9.

*Tests of Liquid Insulation.* Development of tests primarily applicable to circuit breaker oils, such as the determination of gas formed during arcover, measurement of carbon formed and precipitated during arcover, and a rest for amount of water precipitated or emulsified during arcover; also low-temperature viscosities. Studies of the following tests of insulating oils: Neutralization value of both new and used oils; resistance of insulating oils to oxidation (sludge tests), tests for moisture content and for saponification value. Consideration being given to tests for cable oils. Methods for sampling both used and unused insulating oils adopted. Progress reported of work on neutralization number and sludge tests, see A.S.T.M. *Proceedings*, Vol. 33, Part I, p. 400 (1933); also preprint, 1934 report of committee *D*-9.

*Tests of Insulating Compounds.* Investigation of methods of test for solid filling and treating compounds used for electrical insulation, including: Coefficient of expansion; determination of insulation-resistance temperature characteristics; specimens and tests for dielectric strength; also viscosity tests of high melting asphaltic compounds. Procedures developed for measuring coefficient of expansion and for power factor and dielectric strength, see preprint, 1934 report of committee *D*-9.

*Power Factor and Resistivity of Insulating Materials.* Development and preparation of test methods for measuring dielectric constant and

## Control Board of Radio City Music Hall Stage



MANY of those who will attend the Institute's 1935 winter convention to be held in New York, N. Y., January 22–25, will visit the International Music Hall at Radio City. The control board for the stage of this theater is shown here; from this point on the stage, the mechanism of what is reported to be the world's largest stage is operated. Three giant hydraulic plunger elevators that can be lowered 30 feet below stage level and raised 15 feet above stage level make up the huge stage. Built into all 3 elevators is a sectional revolving stage. Thus, when the 3 stage elevators are locked together electrically, they travel as one elevator with revolving stage working while the elevators are going up or down as a unit. The control board of the huge contour curtain that masks the proscenium is also shown, illustrating the method of gaining any contour desired by presetting the 13 push buttons controlling the 13 motors that raise and lower the curtain.

power factor of liquid insulation and of solid insulating materials. Resistivity methods for liquid and solid insulation adopted, also procedures developed for power factor and dielectric strength of solid insulation at 100 to 1,500 kilocycles, 1,000 cycles, and 25 to 60 cycles. See preprint, 1934 report of committee *D*-9. In connection with this work see papers by W. B. Kouwenhoven and L. W. Marks on "A Comparison of the Methods for Testing Insulating Materials for Power Factor and Dielectric Constant at 1,000 Cycles" and by P. H. Dike, W. B. Kouwenhoven, and J. B. McCurley on "Methods of Measurement of Dielectric Characteristics at Commercial Frequencies," issued [by A.S.T.M.] separately.

*Tests of Mica Products.* Study of methods covering mica for capacitor manufacture and built-up pasted mica for general insulating purposes. Tentative methods prepared for grading natural mica and tests for pasted mica, see preprint, 1934 report of committee *D*-9.

*Properties of Electrical Slate.* Study of the properties of slate for use in electrical work. Consideration being given to methods for electrical quality and impact tests. No report available.

# Finding Work*

**An authoritative dissertation dealing in a practical way with the important problem of finding work, and keeping it after it is found. This article was written by Samuel S. Board, placement specialist of New York, N. Y., for the American Society of Mechanical Engineers. Because of its general interest and value it is republished here in full.**

THERE are very few men out of work today who have not made the rounds of companies with which they are familiar, of friends, and of organizations which list jobs; many of them have tried the methods which other men have used successfully; and yet they have not been placed or they have taken wholly inadequate positions. There is no patent method which will reach the needs of all of these men. The techniques of finding work have been tried repeatedly, and while there may be variations in the end the same procedure must be adopted.

No claim is made for originality in connection with the suggestions which follow. They involve merely a restatement of the *whole* process which must be followed in finding work when it isn't easily available. By a careful check as to what you or any one else has done in attempting to secure work, you may find *some* point which you have overlooked or some little thing which is wrong and which is enough to make the difference between success and failure.

Some years ago a really able sales manager lost his job because of difficulties in the company for which he had worked and finally came to me to check over his procedure in securing a new one. He had tried for several jobs and had been turned down in favor of some one else each time. He realized that something must be wrong but had not been able to determine just what. A careful review of what he had done each time revealed the fact that he had passed the first interview with flying colors but had fallen down on the second. When asked how long this second interview usually lasted he replied that he stayed as long as the prospective employer seemed to want him to—2 hours, 3 hours, or even longer. This seemed to be the difficulty (why, will be explained later), and after he had shortened this interview to 20 minutes or slightly more, he secured the next job for which he applied. This may seem to be a small matter, but it is little things which frequently cause the difficulty. The following article, therefore, is presented so you may check *your* procedure against what might almost be called "standard practice." If you are going to read it at all, I should like to ask you to read it through, even though some of it may seem irrelevant to your particular situation.

### Distinguishing Factors in the Engineer's Problem

Despite the fact that most elements in the situation facing the engineer seeking work are similar to those facing other men, there are some which differentiate him from other groups of the unemployed. All of these elements will be found separately confronting some other group, but it is the combination which is certainly distinctive.

One of the most important of these is the fact that the engineer is so often employed by the job. Of course, laborers and artisans and sometimes such semi-professional workers as accountants are employed in this fashion, but on the whole men of comparable grade and ability such as major and minor production executives, salesmen, credit men, purchasing agents, and so forth, work not by the job but for an indefinite period until business contracts, the organization changes, or they fail to grow with sufficient rapidity to keep up with the requirements of the work. This means that whereas the other professional or semi-professional men may give their attention in the main, to "making good" on the job, the engineer must usually keep his eyes open for the next job. During such a period as that between 1923 and 1929, this may be largely unnecessary, since the demand for men of real ability is greater than the supply, but even under such circumstances the engineer, especially the young engineer, may be out of work for a period of from 2 weeks to 3 months. Such a lapse is a tremendous economic loss when the total time is figured.

This problem is, of course, intensified during depressions. While many other types of workers are "carried" by their firms even when work is slack, the engineer is likely to be laid off as soon as the need for his services has passed, especially if he has been with the firm a comparatively short time. There is, on this account, an especial reason for his attempting to work out an orderly method of advancement and for his learning the technique of selling his services when a change is necessary.

For some reason—perhaps because they are more used to studying materials and processes than people—many engineers seem to have little understanding of the fact that there *is* such a technique. Even sales engineers fail to study this question from a sales standpoint. The importance of making it a study, however, cannot be overemphasized.

Back in 1928, the president of a good-sized Chicago company telegraphed my office that he would be in New York the following day and wanted to see 3 sales engineers out of which he would pick one. Three good men were corralled for him and were duly interviewed. Afterward, the one I myself had rated as best in experience and ability came in and said that he had the job. (Those were the days when employers did not feel that they had to negotiate for 6 weeks or 6 months before employing men.) Long experience had made me skeptical regarding the validity of any hiring on the basis of a 3/4 hour interview so I asked the engineer how he got the job. He laughed and said, "Well, I discovered in the first 2 minutes that he was an enthusiast about small boats. I've handled and sailed them all my life, so we talked 40 minutes about boats and 3 minutes about the job, and I was hired."

Even though you may not think this employer was careful enough, the man *did* understand the principles of selling and applied them successfully. Many engineers either do not understand them or fail to use them when their own future is the subject of discussion.

A third distinguishing factor in the engineer's situation is connected with the cyclical variations of business activity. Frequent reference is made to the "business cycle" as if the variations were the same for all industries, when as a matter of fact the curve which is referred to is a composite of many curves which vary in periodicity and intensity. A great many engineers are employed in connection with the heavy industries and the building trades. While some of these, at least, have longer cycles, the intensity of the swing is greater and therefore the unemployment is more severe. Many engineers also are employed in the developmental side of business and such work is more likely to take place during business rises or when money is easily available. In mentioning this there is no intention of suggesting that engineers should not engage in such work but merely that these conditions should be reckoned with and an effort made to discount them.

This can be done in several ways. It is possible to specialize as to one's major oc-

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cupation and yet maintain sufficient contact with other types of work so as to shift when the times demand it. Hobbies which may be entirely outside the technical fields have provided depression occupations for engineers. At least 2 engineers of my acquaintance assured me that they made quite satisfactory incomes during the picture-puzzle craze by cutting them out for the high-class shops on the jig saws that were a part of their home workshops.

A sounder method, however, would be, I believe, for men who have worked for the larger companies and on larger projects to search out smaller manufacturers when times get slow and give them the benefit of engineering knowledge, since small plants, if efficiently managed, can adapt themselves more easily to changed conditions than can the larger ones and can hire experts when they are available, without upsetting a general policy.

One Connecticut manufacturer told me that he saved 60 per cent of his fuel bill one year during the depression by putting 2 young mechanical engineers on a job ordinarily done by laborers and then getting them to show the others how to do it properly. This sounds almost fantastic, but his plant made money that year when other similar ones did not. Of course, the biggest difficulty in undertaking to make a job like this, when one is not obvious, is that of "selling" these small employers. Many of them are not so intelligent or progressive as the one mentioned, but it can be done.

The differences just reviewed between the problem of the unemployed engineer and that of another educated man are not really so large, but they should be considered in devising any real attack on the unemployment problem of the engineering group. Even though this is so the attack must be along the same general lines as should be followed by any man out of work. Essentially, the problem for the individual is the problem of salesmanship. He must first determine the value and uses of what he has to offer. Then he must find a market, and, finally, he must outline an advertising and selling campaign which will inform possible buyers of the value of his wares in such a fashion as to make them pay real money for them. This is a simplification of the procedure which will be outlined in the remainder of this discussion.

### What the Engineer Has to Offer

As has been stated, the first step which must be taken in selling a man's services as in selling a product is to determine what he has to offer. Something of an analogy is offered in the development and marketing of cellophane. According to the information at my disposal this was one of a number of products developed by the du Pont laboratories to use up the nitrocellulose left after the War. The government took most of its share out to sea and dumped it after caching a certain amount for future emergencies; but the du Pont company, being a private concern, did not feel it could do this and set its technicians at work to find other uses for it. Cellophane was one of the results. Even after it was ready for production the laboratories and the sales force had to study its uses, alter its composition to meet new requirements, and determine its tensile strength and ability to resist moisture. If they had not done a thorough job on that phase of the marketing, the phenomenal increase in its use could not possibly have taken place. Now they even make women's dresses of it.

Let us pursue somewhat the same method in determining what the engineer has to offer. In the first place, nearly every trained man has 2 antithetical advantages in amounts which are in inverse ratio to each other. Either he has youth and is relatively inexperienced, or he is more mature and has more experience. I suppose there is a middle ground somewhere in the early thirties when he has both youth and experience in considerable measure but the exact point of balance is hard to determine and is not important. Young men do come to me though and complain that they cannot get work because they lack experience. Older men are discouraged because (they say) the world is looking for young men. Both are wrong. The young man can find certain work where experience is unimportant and the older men can find it where maturity and experience are assets. The mistake both make is in trying to reverse their positions.

In the main, I think it is safe to say that large corporations tend to look for younger men, while smaller companies or new businesses are likely to seek men of more maturity who can take responsibility rather quickly. However, if you are young, you can sell the idea of youth and enthusiasm and the desire to work under some one who knows what it is all about.

If you are older, you can emphasize the value of your experience, the importance of your past positions, and the maturity and seasoned knowledge which you can bring to the job.

If you must seek work outside your own field it will mean, of course, that you must break down your experience into functions performed, in order to discover those easily adaptable to other types of work. For example, a mechanical engineer may be thought of to the world outside of the engineering fraternity in terms of the construction and operation of machines and power plants, whereas, you know that a mechanical engineer may be a designer, an operating superintendent, a test engineer, a sales engineer, a manufacturing executive, a production engineer, a research worker, and a lot of other things that I may not know. Moreover, there are designers of turbines, of automatic machinery, of fine tools, of automobile and airplane engines, and an almost infinite variety of machines and products. All these different types of work involve variations in interest and ability which can be used in describing your abilities along other lines. I do not mean to infer, of course, that what you have done in the past limits what you may do in the future, but the experience and abilities you know you possess may at least be used as a means of transition and should be so used.

Many men who are forced to seek work outside their immediate field try to make, as they say, a clean break and secure something which is entirely unrelated to what they have done before. Even though this may be a natural reaction it is an expensive method, since it usually means taking a beginner's wage. However, if you are willing to take a job in which some of your former experience can be used you can obtain substantially more and then later on take another step farther away and continue that process until a satisfactory occupation is reached.

In any event the only common denominators between jobs are the activities which are involved in these jobs. Any man who can do fine work with tools in one line can probably do similar work with difficult tools in another line. A person who is used to assembling and interpreting data can, at least with some training, take up this activity in another field. A man who is used to handling workers in one type of factory will not have much trouble learning to handle people elsewhere. Have you thrived best where action was involved? Seek action in a new job. Some day a dictionary of work functions will be prepared and then the task will be simpler. Meanwhile we must interpret our own past activities in terms of new jobs, just as we would describe what a product would do.

### Importance of Appearance

The next most important phase of the study we are making is that having to do with what compares to the appearance, fiber, form, and shape of a product. In other words we must be prepared to describe the physical and mental equipment, the appearance, and the personality of the man in question. It is much more difficult for a man to do this for himself than for him to describe and study his experience or his specific work aptitudes. Yet it must be done since no job specification is written without including some of these factors, and to determine whether we meet these qualifications we must have some idea as to just what specifications we can meet.

It is also important as a preparation for the interview by which we may attempt to sell our services. In any such interview, a good share of the impression we make will be governed by what is termed our personality. This includes general appearance, clothes, voice, language, timidity or aggressiveness, and responsiveness to ideas. Of course, there are some things in this category that we just cannot change and these are the points on which men are prone to dwell in their own thinking. After we are 20, for instance, we can't add to or detract from our height, and most of us haven't come to the point, even if some bandits and the ladies have, of employing plastic surgeons to alter our faces. We can, however, even with limited means, be sure that our clothes are suitable and in order, that we look well-groomed, that our expression is alive, our faces mobile, our voices resonant, and our bearing alert.

Some engineers seem to feel that paying attention to personal appearance smacks of the beauty parlor, but that is all tommyrot. Being sure your appearance is suitable is what counts. It wouldn't be safe to go out on many engineering jobs wearing spats and carrying a cane, but these accouterments are an advantage on some jobs. Neither is it suitable to apply for an office job looking like a tramp or to ask for work on a relief project looking like a million dollars. One of the most pathetic stories of the depression has to do with an instance of this. It seems that an elderly clerk, who had worked for years in the financial district only to be laid off in the early part of the depression, was

literally destitute. He and his wife were starving when some one told him about a relief job that he might get the next morning. By this time his clothes were rather shabby but his wife sat up all that night sponging and pressing his only decent suit so that he would be presentable. She did too good a job, however, because when he applied for the relief job he looked so prosperous that they would not believe that he needed help and refused to do anything for him.

You really must dress and act the part in applying for any job, and the first step in doing this is to appraise your usual appearance, your personal assets and liabilities. It is comparatively easy to compensate for or remove liabilities and it gives you so much more confidence if you are aware of your assets.

### Making a Personal Appraisal

There is one great danger in this matter of personal appraisal and that is the possibility of its degeneration into introspection. This will be very likely to happen if you try to assemble all these facts you have been gathering in your head. It just cannot be done properly that way. While you are considering one set of facts, another will be disregarded, and *vice versa*. The only safe way is to organize it carefully on paper. In order to make this easier an account is given of just how this recording may be done.

Let us start with your experience. I should prefer to start with the personal qualifications just mentioned, but it is a little easier, apparently, for most men to start the other way. In listing your experience take it in the reverse order, starting with what you have just been doing and working backward. Put down what you did, the firm's name, the length of your stay, and the range of salary you received. Then break down the jobs and list the various activities involved—whether you hired men, laid out work, figured costs, did a certain kind of designing, or what not. If your experience has been diverse enough, you may find it desirable to rearrange these bits of experience and find out just how much time you have spent in each activity.

If you are younger or had an interesting and varied school experience, it may pay you also to go back and analyze that in the same way. Perhaps there were abilities uncovered then which you have not used since. The same procedure should be followed for your avocational and family interests. Try to remember your activities along all these lines in 1933, 1932, 1927, and 1925, for instance. Throughout this whole analysis a keen watch should be kept for trends in experience and avenues of growth. The possibility of finding these is one reason for arranging the data in chronological order.

Next, your personal characteristics should be described in as objective a way as possible, depending more upon what other people say about you than upon your own estimate. Of course, your mental assets can be gaged in some measure by your scholastic record and the recognition you have received since. It isn't wise to ignore your important liabilities, but emphasis should be kept on the positive side.

You should then have a pretty good picture of yourself and what you can do best. The next thing is to decide what types of work you would like in the future and under what conditions. There may not be much difference between some of them, but it makes it easier to grade them as to desirability, when possible, and put it all down on paper.

Of course, none of these may be possible immediately and they may not even exist as jobs. Men have come in to me and spent several minutes describing the sort of work that they desired and then I have had to tell them in the end that the job just did not exist as far as I knew. They have simply made a synthetic job out of their desires. You will be able to determine this for yourself if you will leave the personal question for a while and consider what functional types of work are open. Since we are concerned at the moment with engineers, I shall try to discuss the markets for the services of engineers even though this must be done in general terms.

### Types of Work Open to Engineers

It is easy to talk about engineers as if they were a peculiar race of men, set apart somehow and separate from the undistinguished rest of mankind, but I refuse to treat them that way. To me they are much like other men. They have the same domestic problems, the same desire for power and for money, the same urge to serve their fellowmen that others have. They may have these in degrees which vary from the degrees which others have them but in general they are just people, despite their scientific training and the wizardry which they sometimes seem to others to possess. So, also, the work that they do does not vary greatly from the tasks that occupy other people. In fact, they enter all sorts of occupations and professions. I know men trained as engineers who are accountants, lawyers, salesmen, artists, politicians, and, I think I might add, ministers. Some of them have discarded engineering as a profession but many have merely combined it with other activities. Nevertheless, there are certain types of work in which engineers are ordinarily found, and, if we are to discuss at all adequately the opportunities for engineers seeking work, it seems the obvious thing to do to cover this better known ground first. I propose to do this on a functional basis instead of using the usual method of dividing the varieties of work according to the engineering degrees of the men who most commonly undertake these tasks.

### Getting Things Done

Suppose we consider the engineer first as an operating man. He gets things done. Usually he will be found in command of at least a small group of men. Perhaps his greatest satisfaction comes from seeing the results of his labors—so many cars turned out each week, or so many barrels of gasoline, or a bridge farther along toward completion, a building built, a railroad kept running, or a communication system kept in operation. His is the brain that checks on the labor of others, that corrects mistakes and surmounts difficulties, that tells how and where and with what tools a task is to be done. In this group come primarily the civil engineers, the construction men, and the mechanical and electrical engineers—all of them types of engineers who have found it especially difficult to get jobs in the fields in which they customarily work during these hard years. We have not, except as the government has been pouring out funds, been building very much. Many of these men are in the so-called capital goods industries, in which the index of employment is still abnormally low.

If you are in this field of activity or have been and your genius is getting things done and in producing tangible goods, why not turn to the other operating fields and see if there are not more opportunities? Plants need to be run as well as constructed and in times past many men who have designed plants and built them have stayed to operate them. Moreover, with more stabilized prices and increased mechanization the operation of plants and factories should and will demand more technical skill on the part of those in authority.

Most engineers understand machines and are fascinated by them. There is no reason why they should not extend their field of usefulness into a great many industries in which the "rule of thumb" is still the governing principle. It is foolish for an engineer, if he is competent, to think that he needs to have experience in any particular industry to do the work necessary in that industry. A few years ago a manufacturer of a rather complicated machine, wanted a factory superintendent. It was specified, however, that any one applying for the position must have had casehardening experience, since that was an important part of the manufacturing process. A competent engineer of my acquaintance felt that he could handle the job even though he had not had such experience. Before applying for the position, however, he spent three days in the New York Public Library reading up on all the latest developments in casehardening. He found out so much about the problems involved that he secured the position in spite of competition with experienced men and even though he frankly confessed his lack of actual experience in the field. He did a good job, too. We are sometimes afraid of the bug-a-boo of specific experience. We ought instead to realize that a man with a trained mind who is not afraid to tackle new problems and is not too diffident about seeking information can bring a valuable and often fresh point of view to the solution of problems that have not been properly solved, because they are too greatly bound around with traditions of what has been done in the past.

There is one phase of an operating job, however, which bothers a good many engineers and to which they need to give close attention. That is the human factor. It simply isn't possible to treat men and women as you do machines. Allowance must be made for individual differences, for prejudices, for ambitions, and for fixed ideas. A certain amount of inspiration as well as consideration, must come from the man responsible for supervision. Scientific management, which is, I take it, principally the application of engineering principles to human productive activity, must sometimes go slowly and allow for the absorption of ideas, in order to save time and money in the end. The engineer's impatience with human frailties seems to be the greatest limiting factor to his usefulness as an operating man.

There is another factor in operating, how-

ever, which favors the engineer. Even though the introduction of machinery has reduced the number of workers in many industries, it has increased the need for maintenance engineers who must see that these machines run, are operated properly, and are kept in good condition. Just after I had finished a period of employment as a machine operator, a well-known psychologist told me that it would not be very long before all machines would be automatic and would be run by morons, meaning, of course, people with less than average intelligence. I was highly indignant at the time because I had come to realize by actual experience that, whereas the manual labor necessary is undoubtedly reduced by automatic machinery and the time necessary to learn the procedure may be cut down to a negligible period, understanding the operation of the machines and being able to act correctly in an emergency requires a high order of intelligence, at least of a certain kind. It also involves a thoroughly trained person to correct difficulties when they occur. Moreover, modern production processes are so closely interrelated that the overproduction of one part or the breakdown of one machine may upset the schedule of a whole factory or series of factories. Here, in the more accurate coördination of production, lies a large opportunity for the trained mind of the engineer. It may be necessary to sell this idea more thoroughly to manufacturers and perhaps you as an unemployed engineer can have a very definite part in so doing. It certainly can be done.

### Research

We must proceed to discuss some of the other phases of work commonly done by engineers and perhaps the next one which should be mentioned is that of research. Business men have come more and more to appreciate the practical results of research even when it seems most remote from the work in hand and scholars engaged in research are coming to appreciate the fact that the pursuit of new knowledge may be profitable financially as well as intellectually. Surely, much progress has been made in a better understanding of the possibilities of research when one of the foremost leaders of industrial research announces that a part of his staff has been engaged for some time in trying to solve the riddle of why grass is green! This, in spite of the fact that there is no apparent connection between this field of research and the products produced by his organization.

Research today, as most of us know it, takes on a multitude of forms. It may involve the experimental design of new machinery, extensive microphotography, the careful analysis of new and old materials, the accumulation and sorting of information from a multitude of sources in order to determine which may provide a vital clue to an entirely new procedure. Many men haven't the patience for such work, they can't stand the inaction, or, most of all, they haven't the controlled imagination.

It is a mistake, however, to think that all such work is done in the universities or in the big corporation laboratories. Much valuable research has been done in lofts, in small shops, or in private laboratories. To discover these smaller enterprises requires something of the instincts of a ferret. They must be searched out, followed up patiently, and approached with caution. Much of this work is not profitable from a monetary standpoint or from the point of view of results, but if you have that type of mind and will apply the same techniques to the discovery of opportunities to be associated with such ventures as you would use in other research, they can be found and are probably not much more hazardous financially than a host of other occupations. Such work is entitled to be called professional from almost any aspect.

### The Consulting Engineer

Of all the work that an engineer does, however, that of the consulting engineer is probably nearest to a completely professional status. Also, it involves some of the most varied abilities. The good consulting engineer must have the analytical ability of the research man, the operating skill and ability to handle people of the operating man, and the enthusiasm and the financial acumen of a good banker or controller. He must keep in touch with new ideas and yet have a comprehensive knowledge of what has gone before. Above all else he must have the ability to plan the expenditure of his own time. Does this sound like a large order? Well, it is.

Perhaps the good consulting engineer comes nearer to being a master of his field than any one else. Excellent engineers who can do splendid work as employees find themselves unwilling or unable to assume the responsibility of independent action. Others lack the ability to sell their services to prospective clients. It is likely to be either a feast or a famine. Either a consulting engineer is so busy that he cannot handle the work and finds it difficult to hire other men who will do it efficiently, or he has time on his hands and has to employ all the arts of a salesman to get enough business to provide him a living. Some engineers find the answer in supplementary occupations, such as teaching, the management of organizations, or through a regular consulting arrangement on recurring problems. The best consulting engineers I have known have been men who have worked for others on a variety of problems, frequently in various parts of the world, and then, after they have had the benefit of this experience, have settled down in some central location to make their experience available to whoever have problems to solve. They are men with standing and prestige who are recognized as authorities. Business in good times naturally flows to them. In poor times they live on their accumulated savings or go into other lines of work. Sometimes they tighten their belts.

It would be possible, and perhaps profitable at another time, to analyze the requirements of a consulting engineer's work more fully, but the present (the fall, 1934), when we are partly through a depression, is not a time when it is possible for very many to enter this field, and there are other possibilities for engineers which should be given more attention.

### Sales Engineering

One of the principal fields of work for engineers outside of what may be called straight engineering is that of sales or sales engineering. Many engineers have tried to go into nontechnical selling without much success, but increasingly, products of a technical nature are demanding engineers to sell them, even some which may be classed as "consumer goods." There are large numbers of machines and basic materials—metals, chemicals, rubber, fabrics—which are used in manufacturing and which must be sold by men who can appreciate their uses and help adapt them to various mechanical situations.

Many men, especially engineers, say and feel that they cannot sell. Some, of course, cannot, but the main reason why the others feel that they cannot is because they think of selling as peddling, or as forcing on buyers things which they do not want and cannot use. True selling is almost the reverse and consists of so appreciating the problems, needs, and personality of the buyer as to be able to make him see, understand, and want the product being offered to him. If it is not desirable and useful in a given situation it should not be sold.

Let us analyze this statement a little further. In the first place, a salesman must study and understand the problems of the buyer. This involves learning as much about his needs as is possible ahead of time; then gathering by skilful questioning of the purchaser more information, including his own prejudices in the matter. Second, it is necessary to understand the buyer himself, to apprehend—there isn't any other word for it—his thoughts and thought processes. Third, the salesman must "get his ideas across" to the buyer convincingly and persuade him to make a decision; get him to "sign on the dotted line." This does not involve "high-pressure" selling necessarily. It merely means creating a sufficient desire and then letting the buyer take the initiative. If the salesman is interested sufficiently in people and is sufficiently interesting to them to get their good-will, the rest of the selling technique can be learned.

Many men think that it makes no difference what they select to sell, but my experience indicates that it makes a lot of difference to the beginner, at least, since, to sell convincingly, most beginners must understand, like, and believe in the product. There is a big field for engineers here, however. As competition becomes keener in this country and prices become better standardized, the art of selling will be more and more necessary, and those understanding it will be in greater demand. Pick your line, pick your company, and you can frequently sell them the idea of taking you on.

One more point regarding sales work should be discussed briefly; that is, the methods of paying salesmen. At the risk of being seriously challenged, I should like to say that most worthwhile selling jobs today pay a salary, or a salary and a commission. If a sales job does not do so, the employer is asking the salesman to take most of the risk. A drawing account is something of a compromise. The salesman is paid a commission but is allowed to "draw" a fixed sum every week or month which is deducted from the commissions he earns. If after a certain period he has drawn more than he has earned in commissions, he is supposed to make up the difference. The company does not always demand this if it is felt that the drop in earnings is

not the salesman's fault, but it is considered an obligation and therefore should be set at the start at an amount which is a little less than the expected earnings from commissions.

Many types of goods and services are sold on a commission basis and some men prefer this basis because of the larger percentage given but it is a particularly harassing method of pay for a man who is methodical in nature. Most companies selling staple articles or articles which involve large unit costs, such as machinery, prefer to pay their salesmen salaries which net them a smaller percentage on their sales if they are successful, but, of course, do not involve so much uncertainty.

It has been pointed out that a salesman needs to be careful about his appearance. He does not need to be unpleasantly aggressive, but he must be well dressed and persistent enough to get a hearing. He must understand people sufficiently to make himself liked and easily understood—persistent but not a pest, in other words.

ENGINEERS IN BUSINESS

In addition to the foregoing functions of engineering which are generally recognized there are opportunities in other phases of business also. Many engineers, especially industrial engineers, eventually transfer to financial positions, such as controllerships. Others secure places for themselves as technical advisers to banks and accounting firms. These positions are likely to be a step beyond consulting work instead of a prelude to it. Others, who are interested in people and their efficiency, go into the personnel field. Many purchasing agents are engineers. Lately, a number of mechanical engineers have entered the planning departments of retail stores in which the handling of goods from the receiving office to the customer is, in many cases, an engineering problem. There are also places for engineers in the editing of technical magazines and books, and many go into various phases of the civil service.

It would be impossible within the limits of this article to give detailed analyses from a functional standpoint of all these various business and public occupations into which some engineers go, and which do offer a wide variety of opportunity if properly investigated. There are numerous books describing them and if these are carefully studied the information can be obtained from them. There are certain of these occupations about which I shall attempt to comment briefly, however, because the information may not be obtainable elsewhere. One of these is banking.

After a good many years' study I am convinced that the only way for an engineer to become connected with a bank in the capacity of adviser on industrial problems is either to become acquainted socially with one of the bank officers, or, more properly, and I think more easily, for him to meet the bank officials in the discussion of a problem in which the bank is interested. Bankers who are impressed by an engineer's handling of an analysis or by his solution of an operating problem will, at times, seek his help with other problems, and, in order to avoid paying a heavy consulting fee, will take him on at a substantial salary. To be able to create this opportunity for himself a man must have a flair for finance because he must be able to talk the language of the banker and because the financial aspect of the problem is likely to play a considerable part in the work he is asked to do.

Purchasing is a distinct career which is usually entered early in life. There are, however, instances in which engineers have been able to secure such opportunities later. This is especially true when they have been engaged in industrial reorganization. In order to purchase successfully, a man must have an almost unlimited capacity for absorbing detail without being swamped by it, must be interested in and understand markets, must be able to understand but not necessarily to like people, although that is a help. His judgment and ability to decide promptly must be excellent and he must be able to make decisions without worrying about them. A purchasing agent can many times put a firm "in the black" or "in the red" simply by buying at the right time and in the right quantity.

Planning departments are likely to assume the aspect of boards of strategy. They have to do with the flow of goods and work in process, with plant layout, and, with questions of management policy. This field is a good example of special jobs in which engineers are finding places.

Another job is that of building superintendent. In smaller buildings this may not be far removed from the work of a janitor, but in larger buildings the problem of mechanical upkeep makes an engineering training desirable, so that both mechanical and structural engineers will be found carrying on this work with success.

Nothing has been said so far regarding strange or unusual jobs which engineers have undertaken. There are many of them, but such possibilities are discovered either by chance or by an analysis of the individual's special interests. What has been attempted is a review, from somewhat of a functional standpoint, of the occupations usually open to engineers, in the hope that those who are unemployed may find something they have overlooked.

**EDITOR'S NOTE:** Although this important article is being republished in full in ELECTRICAL ENGINEERING, space limitations require that it be presented in two parts; the second and concluding part is scheduled for inclusion in the January 1935 issue.

**A.S.C.E. Officers for 1935 Nominated.** The complete roster of official nominees for offices in the American Society of Civil Engineers for the year 1935 has been announced. Arthur S. Tuttle of New York, N. Y., has been nominated for president. Mr. Tuttle is widely known not only because of his activities in the A.S.C.E., but also because of his important engineering experience, particularly with the board of estimates and apportionments of New York City, from which he retired in 1928 as chief engineer after 26 years of service. Continuing as consulting engineer, he also has recently served as New York State engineer for the Federal Emergency Administration of Public Works. For vice president, D. H. Sawyer of Washington, D. C., was nominated to represent Zone 2; and Henry E. Riggs, of Ann Arbor, Mich., to represent Zone 3. For directors, each representing a separate district of the A.S.C.E., the following were nominated: C. Arthur Poole, Rochester, N. Y.; HERMAN STABLER (A'04, M'13) Washington, D. C.; James L. Ferebee, Madison, Wis.; Charles B. Burdick, Chicago, Ill.; H. S. Morse, Indianapolis, Ind.; Ivan C. Crawford, Moscow, Idaho; and Theodore A. Leisen, Omaha, Neb. The tellers' report on the results of the ballot will be announced during the A.S.C.E. annual meeting, Jan. 16–19, 1935. Those elected take office immediately.

## Outdoor Weathering of Metals and Coatings

A book has been prepared containing the papers and discussions presented as part of a symposium on the outdoor weathering of metals and metallic coatings, held at the 5th regional meeting of the American Society for Testing Materials, Washington, D. C., March 7, 1934. This symposium evaluates much of the performance data obtained from the extensive outdoor weathering tests carried out by the Society's committees *A*-5 on corrosion of iron and steel and *B*-3 on corrosion of nonferrous metals and alloys. The symposium is intended to illustrate applications of A.S.-T.M. corrosion test data in solving materials problems, but the authors of the 5 extensive technical papers did not confine them to data or official conclusions of the 2 corrosion committees.

The papers discuss the following subjects: outdoor test results on bare and metal-coated ferrous specimens; the harmony of outdoor weathering tests; influence of rainfall and smoke on the corrosion of iron and steel; early interpretation of test results in the atmospheric corrosion of nonferrous metals and alloys; and galvanic corrosion by contact of dissimilar metals.

An interpretation of corrosion test results necessarily introduces various viewpoints. The very considerable portion of the publication devoted to discussion thus gives a broader view of the field. Extensive contributions from technologists in England indicate interesting results of widespread test programs conducted there and comparisons with conclusions reached in this country.

Much of the data are given in concise form through charts and tables and appropriate illustrations enhance the utility of the book. Copies of this 113 page book can be obtained from A.S.T.M. headquarters, 260 S. Broad St., Philadelphia, at $1.25 per copy, heavy paper cover; $1.50 in cloth.

**American Physical Society Annual Meeting.** The annual meeting of the American Physical Society will be held at Pittsburgh, Pa., December 27–29, 1934. This meeting will be held concurrently with the Annual Science Exhibition to be located in the Mellon Institute Building, Pittsburgh, Dec. 27–30, 1934. This exhibit, which was announced in ELECTRICAL ENGINEERING for September 1934, p. 1327, is sponsored by the American Association for the Advancement of Science and Associated Societies.

## How to Use Electronic Tubes in Industry

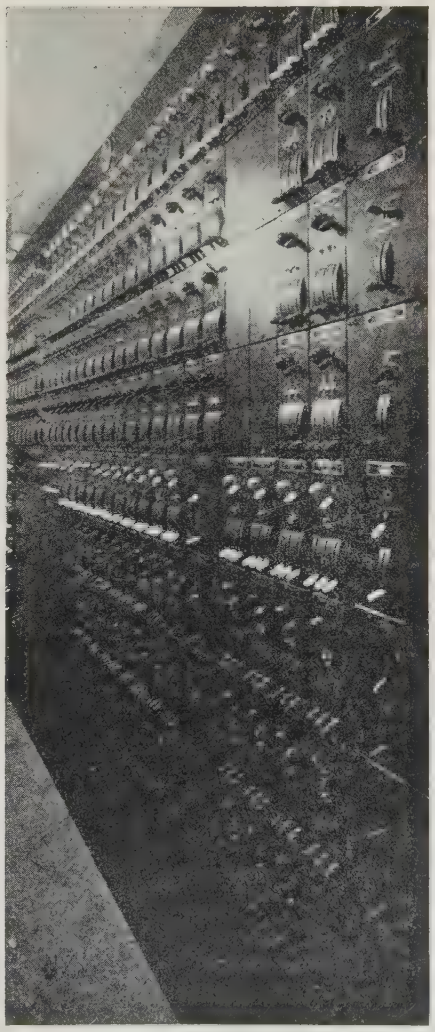
A pamphlet entitled "Industrial Electronic Tubes" has been prepared, which presents a fundamental treatment of the operation and the application of electronic tubes in industry. The treatment is nonmathematical, starting with electronic phenomena and the mercury arc, passing to high vacuum tubes and the grid glow family, thence to photo-responsive electronic devices and cathode ray tubes and ending with the specific technique of a variety of applications. Throughout the pages the purpose is to show how the physical properties discussed can be put to practical use in industrial control. It is an illustrated 217 page zincograph pamphlet, prepared under the supervision of the educational department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and offered by them for $2.25 (net).

As a supplement to this pamphlet a "Manual of Experiments" may also be purchased for 65¢; in this series of 24 tests, the apparatus needed, methods of set-up, procedure to be followed, and results to be obtained are fully explained. These experiments parallel the course of study which can be obtained from the larger pamphlet, and demonstrate the type and characteristics of the various electronic tubes described. The 2 may be used as a schedule in this subject of both classroom and laboratory work. It is stated that advertising and propaganda have been carefully avoided so that the material can be used as an accurate and unbiased text.

**France Honors Early Menlo Park Worker.** On April 6, 1934, Francis Jehl, curator of the "Edison Laboratory" in Greenfield Village, Henry Ford's museum at Dearborn, Mich., was honored by the French government when its representative, M. Leon Morand, consul at Detroit, bestowed upon the aged electrical engineer the title of Chevalier of the Legion of Honor. Mr. Jehl is reported to be the only survivor of the small group in Thomas A. Edison's research laboratory in Menlo Park, N. J., of 1878–79. He assisted Edison in the experiments that led to the invention of the first practical incandescent lamp. It is reported that following the successful production of the incandescent lamp and the Edison system, Mr. Jehl installed and started the testing department of the Edison Machine Works in New York City in 1881, and the following year was sent to Europe, where he assisted in starting the French Edison Companies' Lamp Works. He also pioneered in the installation of electric lighting equipment in other parts of Europe. The presentation by the French government of this honor to Mr. Jehl was followed by a brief address by Alex Dow (A'93, F'13, and member for life) who spoke of his early association with Mr. Edison and Mr. Jehl. Mr. Jehl is a son of an officer of the Union Army, whose ancestors migrated from France to America in Colonial days.

## Metropolitan Opera Installs Lighting Control

When the opera season in New York opens on December 24, 1934, occupants of the Metropolitan Opera House will observe for the first time the results of the thorough remodeling and modernization program which has effected numerous improvements to the historic opera house. Most notable of the changes directly affecting the operatic productions is the installation of the most modern type of electronic tube control for both the stage and house lights. This new lighting equipment, employing electron tubes to control the reactor dimming system, was manufactured by the General Electric Company, and will place the control of all lighting effects at the finger tips of one individual. The presetting controller located in the "lighting pit" below the stage is shown here. A hooded opening in the stage floor near the footlights enables the operator to observe the effects produced. To the right of this board, and not shown here, is the master controller. From the lighting pit, each of the 156 circuits for the stage may be independently preset for 3 complete lighting scenes, so that the touch of a button will accomplish the scene-to-scene change of circuits. In addition, the 11 house circuits may be controlled from this point. The presetting controller provides for the individual control of each circuit, while the master controller enables the operator to govern all circuits simultaneously, either for dimming or for blackout, and to split the control into major divisions of color. The circuits are arranged to provide one color for the house and 4 colors for the stage, except for the footlights where 5 colors are to be used. The Metropolitan Opera House is among the large number of places in New York which may be visited during the forthcoming A.I.E.E. 1935 winter convention.



## Engineering Education to Be Reorganized at Harvard

The board of overseers of Harvard University at its last meeting approved action previously taken by the Corporation providing a plan of reorganization of instruction in engineering in the University. This plan, which will become effective in 1935–36, provides that undergraduate instruction in engineering will no longer be given in the engineering school but will thereafter be undertaken solely by the division of engineering sciences in the college, although with the same equipment and under the same officers of instruction as formerly.

The tendency in recent years has been for the majority of students wishing to obtain undergraduate instruction in engineering at Harvard to secure it through the division of engineering sciences in the college rather than by registering as undergraduates in the engineering school, and the administrative change now to be made is in conformance with this tendency.

The engineering school will be continued on a strictly graduate basis, as the graduate school of engineering, with courses in the several branches of engineering leading to the degrees of master of science in engineering and doctor of science.

**Pennsylvania Railroad Orders 57 Locomotives.** Orders for 57 streamlined electric engines, reported to be the most powerful electric passenger locomotives ever built in the world, have been placed by the Pennsylvania Railroad. Costing almost $15,000,000, these new locomotives have been specially designed for high speed passenger service to be inaugurated between New York, Philadelphia, Baltimore, and Washington, early in 1935. They will be capable of making regular operating speeds of 90 miles per hour hauling standard trains. Twelve 57-inch driving wheels will drive the fully streamlined articulated engines along the tracks with full power of 4,620 horsepower at high speed. Each locomotive will be 79.5 feet long, of all steel construction, and will weigh 230 tons. They will operate on an 11,000-volt 25-cycle single-phase system, the current being supplied by overhead wires through a pantograph. The maximum starting tractive effort will be 72,800 pounds. Eighteen complete chassis will be built at the Pennsylvania Railroad's Al-

toona shops, and 25 chassis will be built by the Baldwin Locomotive Works at Eddystone, Pa. The General Electric Company, at Erie, Pa., will build 14 complete locomotives, including chassis and electrical equipment, and in addition will build electric propulsion and control apparatus for 9 other engines. The Westinghouse Electric and Manufacturing Company, at East Pittsburgh, Pa., will build the electric propulsion and control apparatus for 34 locomotives. These latter 2 groups of electrical equipment will be installed by the Pennsylvania Railroad in the 43 chassis built by it and the Baldwin Locomotive Works. In a previous order placed in July 1934, 28 electric passenger engines were ordered by this same railroad at a cost of over $6,000,000.

## Lightning Storms in Northwest Studied

A report "Lightning Storms and Fires in the National Forests of Oregon and Washington" has recently been prepared by W. G. Morris of the Pacific Northwest Forest Experiment Station, Portland, Ore. One thousand copies of this report have been printed and are being sent to forest fire wardens in Oregon and Washington, national forest supervisors and rangers, electric power companies in the northwest, local weather bureau officials, and other interested persons.

In this report, lightning storms in Oregon and Washington, some of which caused 215 forest fires in a single day and traveled at speeds of 1 to 40 miles per hour have been mapped and described. From records taken since 1925 by 200 forest fire lookouts stationed on mountain tops in the national forests of these 2 states, the Pacific Northwest Forest Experiment Station has made the first comprehensive study of mountain lightning storms undertaken in this region. Findings of the study are: the time of day when lightning storms usually occur; direction, length, and rate of lightning storm movement; percentage of lightning flashes which strike the ground; frequency of lightning storms and fires in different parts of the national forest areas, and the relative number of forest fires set on various types of storm days.

Lightning on the national forests of Oregon and Washington causes 750 fires annually, more than $^1/_2$ of the total number. These storms cause enormous damage. Unfortunately, they occur over immense areas and the fires usually start in the most inaccessible places.

Definite zones of lightning storm occurrence have been mapped in Oregon and Washington. However, lightning storms do not follow repeatedly the same lane or track, as for example, certain valleys and ridges. The number of lightning fires per acre at high altitudes is no greater than at low altitudes on most national forests. Most lightning flashes in the mountains of this region are from cloud to cloud. A greater percentage of cloud to ground flashes or strikes occur on days when storms are widespread than on days when storms are localized.

## A 500-Watt Loudspeaker

A new loudspeaker, shown in the illustration, has been developed which is so powerful that it can amplify the human voice one million times, and over flat country still air can be heard a distance of several miles. This loudspeaker is 500 times more powerful than the ordinary loudspeaker, and is intended primarily for outdoor use. The speaker, which was developed by engineers of Bell Telephone Laboratories, Inc., for the Western Electric Company, was recently used at reduced power by the U.S. Coast Guard at the International Yacht Races. The speaker has been designed so that speech projected from it is sharpened so as to penetrate other noise more easily, concentrating its power in the band from 400 to 4,000 cycles. Instructions and warnings can thus be given in many special applications. The amplifier is capable of delivering 1,000 watts of speech current to the loudspeaker, and the speaker of delivering 500 watts of energy to the air. Both the speaker and the microphone which is used with the system are of the "moving coil" type. The speaker and horn combined are 30 in. in diameter by 30 in. deep.

**Unit Air Conditioner Association.** The formation of a new association, the Unit Air Conditioner Manufacturers Association, New York, N. Y., to foster and promote unit air conditioners has just been announced. Preliminary figures indicate that the annual gross sales for last year of unit type of equipment were approximately $4,000,000, and it is estimated that the current year will see this volume exceeded by 50 per cent or more. It is the aim of the association to guide the development of the industry along the proper lines so that the advantages to be gained by public buying will enhance the continued development and use of air conditioning.

**Large Transformer Order Placed.** An order for 7 65,000-kva transformers was placed the latter part of October by the bureau of power and light of the city of Los Angeles, Calif., with the Westinghouse Electric and Manufacturing Company. This order is reported to amount to approximately $1,000,000, and to be the largest single order for transformers placed in the last 5 years. These transformers will be installed at the Los Angeles terminal of the 285-mile 287-kv transmission line from Boulder Dam. Six transformers arranged in 2 banks with one for standby service will step down the voltage to 132 kv. Each unit will weigh nearly 250 tons, stand 35 ft high, and occupy a floor space area of about 19 × 20 ft.

# Standards

## Radio Standardization Sponsorship to Reside Solely in I.R.E.

The sponsorship of the sectional committee on radio, which has been held jointly by the Institute of Radio Engineers and the A.I.E.E. since its inception in 1924, was considered by the standards committee of the A.I.E.E. at its October meeting, and it was recommended that the A.I.E.E. relinquish its joint sponsorship in favor of a sole sponsorship by the I.R.E. This action was approved by the board of directors and the suggestion transmitted to A.S.A.

## Limit of Observable Temperature Rise

At the meeting the A.I.E.E. standards committee held on October 16, 1934, a question was raised relative to the exact meaning of "limit of temperature rise" as it appears in many of the A.I.E.E. standards. It had been suggested that an ambiguity existed. Was it the observable limit or the hot-spot limit to which reference was made? In the minds of the committee there was no question as to the limit referred to, but in order to eliminate any such question the clause will be reworded in all future editions and will appear as "limit of observable temperature rise."

## Standards on Electrical Insulating Materials

A publication of considerable interest to the electrical industry has just been issued by the American Society for Testing Materials entitled, "A.S.T.M. Standards on Electrical Insulating Materials."

This 1934 edition includes in their latest approved form 21 standardized methods of test and 12 specifications. The method of testing molding powder used in manufacturing molded electrical insulators has not been published heretofore. During 1934, revisions were made in a number of the test methods including those covering the following materials used for electrical insulation: varnishes, solid filling and treat-

ing compounds, untreated paper, sheet and plate materials, varnished cloths and cloth tapes, laminated tubes and round rods, and electrical porcelain.

In addition, the following are covered by specifications or tests: flexible varnished tubing, rubber gloves, rubber matting, electrical cotton yarns, silk and cotton tapes, pasted mica, and slate.

Copies of this publication can be obtained from A.S.T.M. Headquarters, 260 So. Broad St., Philadelphia, at $1.75 per copy. Special prices are in effect on orders for 10 or more copies.

### Test Code for Transformers

The "Test Code for Transformers," which was prepared under the auspices of the electrical machinery committee of the Institute and has been available in printed form for comment since October 1931, was ordered transmitted to the American Standards Association for action by the standards committee at its October meeting. The code will be considered by the sectional committee on transformers, together with revisions and additions suggested by the electrical machinery committee.

### Test Code for Polyphase Induction Machines

There has just been received for action at the next meeting of the A.I.E.E. standards committee, a "Preliminary Report on a Proposed Test Code for Polyphase Induction Machines." This has been developed under the auspices of the electrical machinery committee and will probably be ordered published for general comment. Notice of availability of the report will appear in a later issue.

lowing the same philosophy now being exhibited by the leaders in government, that is, we are working on the policy of integrating Council relations, both within and outside the engineering profession and then to relate the integrated whole to the challenging problems of the times. The executive committee and the executive secretary of American Engineering Council have been greatly stimulated by the enthusiasm and renewed purpose with which the present members of Council have supported its work in the past year. Through regular monthly meetings with the secretaries of the National Society members and with corresponding relations with local organizations, there is evident a strength of purpose which is deeply appreciated by those who have been elected to lead the affairs of Council. In this connection, the executive committee is planning to present for consideration of local engineering organizations a plan of membership, which they hope will increase the participation of engineers in national affairs, as well as provide less financial obligation.

## American Engineering Council

### Census of Engineers

A profession-wide survey to show how engineers have fared through the hard times is being made by the U. S. department of labor in coöperation with American Engineering Council and as many of the engineering societies as are willing to participate. Unsigned confidential questionnaire returns from 100,000 individuals will give salary trends, types of employers, and duties over the past several years, plus educational background and other facts designed to give a true picture of the engineers' status. Compilation of returns early in the year will show how our people have adjusted to changing conditions and how many are unemployed or in minor jobs, awaiting placement in regular work. This is believed to be the most comprehensive nation-wide study ever made of a professional group. Results are expected to be of immediate practical application to the engineering employment program; will serve as a check against policies of engineering schools which may be turning out too many graduates in some fields and not enough in lines of current demand. The survey has resulted from negotiations by Council with Dr. Isador Lubin, commissioner of labor statistics, whose Bureau will do the job.

As a statistical backlog for present estimates, Council has made an intensive study of the distribution of engineers among the various industries as of the Census of 1930. 225,000 called themselves engineers, or one to about every 500 of population; one engineer to every 210 persons listed as gainfully employed. Membership of engineering and allied technical societies totaled 115,000 as of 1929 which makes the Census figure look large; it probably includes surveyors, draftsmen, and minor technicians. Arrangements are being made for a better classification in the next Census.

The breakdown by industries is none the less significant. In fact, the exceedingly small ratio of engineers in many industries is the more striking when it is remembered that the count of engineers is probably high. In forestry and agriculture, only 0.01 per cent of the employed are listed as engineers; in wholesale and retail trade, only 0.02 per cent; textile and clothing industries, 0.06 per cent. The figures range up to 3.51 per cent for public utilities. Although Federal work offers the most widespread opportunities at present, it is obvious that the real future of the profession still is in the field of private industry. In 1930, 11 per cent of the 225,000 were employed by governments (Federal, State, and Local); 24 per cent were on a consulting basis, doubtless mainly for private firms; and 65 per cent were employed by industry and commerce. The development of technology in backward industries is the main hope for the profession. Two charts which Council has made available tell the complete statistical story.

### "Integration" of National Activities

The confusion of events affecting the future status of industry and trade has been gradually clarifying over the past several months. There is still much confusion in national policy because of the variety, scope, and varying leadership of governmental activities. If there is one word which may be made the keynote of immediate effort, it is the word "integration." In these activities engineers are playing and have played an important part. American Engineering Council during the past few months has been perfecting its organization plans to fulfill these new and increasing demands for Washington service.

Steps already taken by Council are fol-

### Representative on Employment at Washington

Facilities to aid the placing of men are provided in Washington through the coöperation of the National Engineering Employment Committee to meet the needs of pending Federal plans giving early promise of employment of a large number of engineers, in addition to the thousands already in the Federal service. A special representative of the National Engineering Employment Committee is to be located in Washington. Col. C. H. Crawford has been selected to represent the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers in an effort to aid the government in securing qualified men for engineering work.

Colonel Crawford's efforts will be devoted to the task of becoming acquainted with the government's present and future needs for engineers. He will be in direct contact with the employment committee and for the present all communications regarding opportunities for government service should be sent to the Engineering Societies Employment Service at 29 West 39th Street, New York, N. Y.

### Unemployment Among Engineers

Unemployment of engineers has declined in the past year but still is no small problem. Council recently prepared a rough estimate based on telegraphic returns from the States which have been somewhat substantiated from Federal sources. Conclusion: present unemployment of engineers stands in the magnitude of 30,000.

The field for employment, present and prospective, of engineers in the Federal services, has been probed by a member of Council's staff, who has visited more than 70 government agencies in Washington within the past few weeks.

Council's canvass shows, approximately 15,000 engineers are employed by the regu-

lar and emergency units of the government whereas only about 4,000 were on the rolls before the present administration took office. Substantial numbers also are serving in subprofessional and nonprofessional capacities. A report of the findings for each agency with notes as to employment procedure is being considered for publication purpose: to advise individuals and societies where opportunities exist and where they do not exist; to serve as a guide which will save the time and trouble of seeking Federal placement in the wrong places and in the wrong ways.

# Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

## Engineering Education Should Train 2 Types of Engineers

*To the Editor:*

I have been much interested in several papers on the subject of engineering education which have appeared recently in ELECTRICAL ENGINEERING and particularly in the discussions of 3 of these papers in the October 1934 issue, pages 1413–22. In the hope that the personal experiences of one who has passed through this process of technical training and adjustment to industry at a comparatively recent date may add something to what has already been said on the subject the following observations are offered for your consideration.

Having been interested in electrical science since early boyhood it was natural that I should select electrical engineering as a profession and I accordingly enrolled in the electrical engineering department of a well-known mid-western university in the fall of 1923. As the end of my sophomore year approached, however, I had begun to doubt the ultimate wisdom of my choice. It seemed to me that my personal interests and inclinations were more in the field of executive work in technical industry than in purely technical design or research work and that in order to fit myself properly for the work I wanted that I needed training not offered in the schedule of instruction I was following.

After thinking the matter over during most of the following summer I transferred at the beginning of my junior year to a course in business administration administered by the college of commerce. My idea in making this change was that the required courses in the new curriculum would provide the training missing from the regular engineering course and that by using an increased number of electives to take engineering courses I could fill in the engineering background that I wanted. One semester of this new course, however, was enough to convince me that the required subjects would crowd out too much of the engineering work which I still regarded as the fundamental portion of the training.

At the end of the first semester of my junior year I therefore transferred back to the college of engineering, this time to a course listed in the catalogue as "engineering physics." My selection of this course was based upon the fact that it included fundamental courses in electrical engineering together with advanced courses in mathematics, physics, and chemistry and also a number of electives which would permit me to fill in the so-called liberalizing courses that I wanted. Some of the courses which still could not be wedged into the regular schedule were included by securing permission to take more than the usual number of semester hours of work. This is the course in which I finally secured my degree and which incidentally is a course of instruction intended for the training of research engineers.

Following the completion of my university work 7 years ago I spent 2 years in a training course for junior executives conducted by the organization in which I am now employed. The last 5 years have been devoted to various staff positions.

As I look back over these experiences now 2 things seem to stand out quite clearly. First, that what I was really trying to do and did not quite realize it at the time was to make for myself just such a course of training as that described by L. W. W. Morrow in his paper "Industry Demands and Engineering Education" which appeared in ELECTRICAL ENGINEERING for April 1934, pages 518–22. What I was trying to get was a main stem of engineering and scientific training with the necessary economic and sociological training to fit myself for executive work in technical industry. If a course of this type had been offered, especially one that could have been adapted to the needs, abilities, and inclinations of the individual student as the course progressed I believe that I would have secured a great deal more benefit from the 4 years I spent in college. Second, that with all of the short-comings inherent in the way in which it was necessary for me to fit my university work to my needs I believe, after 5 years of experience, that the training I secured is better adapted to my purpose than a purely technical course in electrical engineering would have been.

Whatever may be the final form of the courses adopted by our leading technical schools it seems evident that a real need has been indicated by this group of papers and that a worth while improvement will necessarily follow.

The suggestion that "honors" courses be provided for the development of professional and technical engineers with the regular curriculum designed for engineers going into general industry seems to me to be an unfortunate choice of terminology. It seems to me to be not so much a question of ability between the 2 types of engineers as it is a question of providing the best possible training for both types. The events of the past few years indicate clearly that the need for problem solving ability in the sociological and economic fields is at least as great as it is in the purely technical phases of engineering work. The most constructive thing to do is to recognize frankly that there are 2 types of engineers of approximately equal importance to society and to provide schedules of instruction that will enable both groups to get the most out of their technical school training.

The most practical suggestion would seem to be for both groups to pursue the same schedule of instruction during the early part of the curriculum and for the individual student to make his choice between the 2 types of work at about the beginning of the junior year. In this way both courses could be developed as an integrated whole and there would be sufficient time during the first 2 years for giving the necessary information and advice to the individual student to enable him to make an intelligent and well-considered choice.

Very truly yours,

T. F. McMains (A'34)
(Chief Operator, Western Union Telegraph Company, Wichita Falls, Texas)

## A New Stroboscope to Study Hunting of a Synchronous Motor

*To the Editor:*

The characteristic of the synchronous motor known as hunting is difficult for the average student to understand because it is hard to visualize what is going on in the machine. However, when the mechanical oscillation between the impressed voltage and induced voltage is converted into the oscillation of a beam of light, hunting becomes much easier to understand. By means of the following simple device this conversion is possible and the angular displacement of the rotor can be seen.

Referring to the diagram, $M_1$ is a small single-phase synchronous motor. $M_2$ is the synchronous motor which is to be tested for hunting. Both motors must have the same number of poles. A thin metal disk about 5 in. in diameter is attached to the shaft of $M_1$. A similar disk is mounted on a single-bearing shaft, the center line of which coincides with the center line of the shaft of $M_1$. The disks are mounted to run as close together as possible. The single-bearing shaft is connected through a flexible coupling to the shaft of $M_2$. A narrow radial slot about 1.5 in. long is cut in each disk. A light mounted as shown in the diagram and a shield to cut off undesirable light complete the stroboscope.

The motors run in opposite directions. When there is no hunting the radial slots

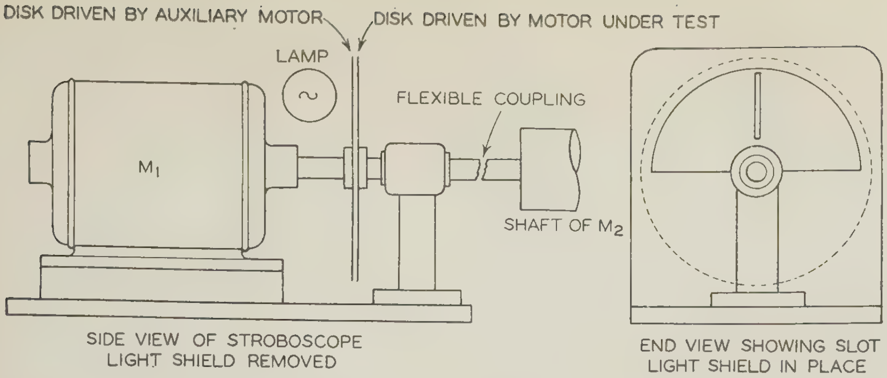



**Fig. 1. Arrangement of stroboscope to study hunting**

will pass each other at the same points each revolution. This allows a beam of light to pass through both disks when the slots pass. Because of the speed, this beam appears stationary and continuous to the eye. When the motor hunts, this beam oscillates through an angle which is approximately equal to the angular displacement in electrical degrees divided by the number of pairs of poles.

In addition to its use when studying hunting, this device shows some interesting facts when used to investigate the pull-in and pull-out torque characteristics of the synchronous motor. It also gives good results when used to determine the slip of an induction motor.

Very truly yours,

E. W. WINKLER (A'30)
(Instructor in Electrical Engineering, University of North Carolina, Chapel Hill)

## Reignition of an Arc at Low Pressures

*To the Editor:*

A recent paper by Mackeown, Bowden and Cobine ("Reignition of an Arc at Low Pressures," ELEC. ENGG., v. 53, 1934, p. 1081–5) describes experiments on a-c arcs at low pressures, and from the results draws certain conclusions about the mechanism of reignition and the transition from glow to arc. Though their theories may seem plausible in a qualitative way, a quantitative test reveals the necessity for additional assumptions so unreasonable as to throw strong doubt upon the correctness of their conclusions.

The results of the present investigations do not really disagree with those of Todd and Browne, (*Phys. Rev.*, v. 36, 1930, p. 732) who found a reignition voltage equal to arc voltage for a 90-amp arc between carbon electrodes at atmospheric pressure: for a low reignition voltage, it is necessary that the old anode-new cathode electrode shall have a temperature sufficient for considerable thermionic emission at current zero; with the low pressures, low currents, this condition was not realized as it was with the higher currents, higher pressure of Todd and Browne.

The intermediate voltage stage of discharge noted by the authors at low pressures may be a type of thermionic arc. It is well known that if the temperature of the cathode of a glow, on tungsten say, is raised the cathode fall decreases in a continuous manner from the normal value with no emission, to the low voltage of an arc when the saturation emission is equal to the total current flowing. The intermediate stages are stable, and may perhaps be classed as a form of arc.

Since the sparking potential in regions near the minimum is sensitive to cathode material and character of gas, the calculated curve used by the authors does not necessarily coincide at all with the true sparking potential for their experimental conditions. This is particularly true for the electrodes containing the rare earths.

The authors apparently hitch their cart before their horse when they invoke the high intensity field which may sustain the cathode *after* the establishment of an arc, to explain the lowering of the reignition voltage. It will be shown below that such fields do not exist in the glow which forms before the arc (clearly seen in Fig. 2 of the paper by MacKeown, Bowden, and Cobine, and probably also existent in all cases where the reignition voltage is high) and of course cannot be a factor in the reignition to a glow. Thermionic emission would lower the reignition potential below the normal sparking potential, and the glow voltage would be lowered to the same degree. At all pressures in Fig. 2, the glow voltage is constant at about 270 volts, both with the low current flowing to the left of $A$ as well as when an arc exists during a part of the half cycle.

A quantitative test of the authors' theory of glow-arc transition may be made. Though unfortunately complete data are not available, still one may attain results of the correct order of magnitude using known characteristics of glows with other materials. Consider the oscillogram for one-centimeter pressure in Fig. 2. A normal glow exists, since the voltage remains constant with change in current, even up to the point at which the transition to arc takes place. The thickness of the cathode fall space is about 0.04 to 0.06 cm, so the average field is roughly 5,000 volts per centimeter; the field at the electrode surface will not be over twice as great, or $10^4$ volts per centimeter. Now according to the theory of high field emission (see paper by Stern, Fowler, and Gossling, Roy. Soc. *Proc.*, A124, 1929, p. 699) in order to secure an emission equal to the emission of electrons by positive ion impact, a field over $2 \times 10^7$ volts per centimeter would be necessary. If high fields are to produce enough emission to begin to affect the glow, then surface irregularities must multiply the gross field by 2,000! Such a large multiplication is entirely unreasonable.

Consider now the other suggestion, that a spot of some impurity exists on the cathode, which yields more electrons than the rest of the cathode. Then, these electrons produce additional positive ions, which produce more electrons, but unless some new ionizing agent enters (high field emission) the process continues only until all the glow is concentrated upon the impurity. If a normal glow exists, the cathode fall is *lower* than before, so the field is weaker, and high field emission is still more improbable. If the current is large and the area of impurity small, an abnormal glow sets in, but the cathode fall is limited to the normal cathode fall of the body of the cathode; if it should rise higher, then all the current would be diverted away from the impurity.

The cathode fall in an abnormal glow is related to the normal fall by

$$V_A - V_N = \frac{A\sqrt{i_a}}{p}$$

where $A$ is a constant, $i_a$ the abnormal current density, and $p$ the pressure. One may set a lower limit for $V_N$ thus: $V_N$ follows roughly the work function, which may be taken as 4 volts on the graphite and a lower limit of 1.5 volts on the impurity, which gives 100 for $V_N$. This is considerably lower than measured values of $V_N$ for the alkalis. The constant $A$ is probably about 100, and $V_A$ is limited to 270. Thus for $p = 1$ cm

$$270 - 100 = \frac{100\sqrt{i_a}}{10}$$

from which $i_a = 189$. The current at the point of transition, from Fig. 2, is about 0.8 amp, so the diameter of the impurity is at least 0.075 cm. It is hardly conceivable that such an area of impurity could exist on supposedly pure graphite. Even if it did, the field would still be insufficient for cold cathode emission. The thickness of the cathode fall space, for such large current densities reduces to

$$d_a = \frac{B}{p}$$

where $B$ has the value about 0.06, so $d_a = 0.006$. The field at the surface is thus about $10^5$ volts per centimeter. Because of the reduced work function, the necessary field is reduced to about $5 \times 10^6$ volts per centimeter $\left(\frac{\varphi^{3/2}}{E}\right) =$ constant). So one must postulate not only an unreasonably large spot of impurity, but also an irregularity upon it giving a field multiplication of 50!

A much more reasonable spot of impurity would consist of a few thousand, or at the most, a few million molecules. Only an extremely small part of the total current could be carried to such a spot, so the remainder of the cathode would be covered by a normal glow as in the absence of the impurity. With so small a spot, the thickness of the cathode fall space over it would not be the $d_a$ calculated above, but almost the normal thickness for the rest of the electrode, so the field at the impurity would be only a little larger than over the adjacent

pure electrode. Thus one must assume coincident with the impurity an irregularity giving a field multiplication of 500.

Thus, the theory of glow-arc transition, which seems to fail in at least the case discussed above, and very likely in many other cases, reduces to a hypothesis which demands quantitative proof of its correctness before it can be accepted. Particularly valuable in extending the knowledge of the reignition of arcs between refractory electrodes at low pressures would be a determination of the sparking potential under the experimental conditions; an observation of anode drop and current density, so the anode (new cathode) temperature might be estimated; and an expansion of the time scale of oscillograms of the reignition region.

Very truly yours,

R. C. Mason (A'26)
(Westinghouse Research Laboratories, E. Pittsburgh, Pa.)

## Arcover Caused by Absorption Current

*To the Editor:*

In the article entitled "Insulator Arcover in Air" by F. W. Maxstadt in the July 1934 issue of Electrical Engineering, p. 1062–8, a certain unexplainable phenomena is noted. Two electrodes with one centimeter spacing show a breakdown strength with air as the dielectric of approximately 30 kv and with a right cylinder of rubber in the field the breakdown strength was reduced to about 15 kv.

It is possible that this phenoma may be explained by the so-called "absorption current" of the rubber sample. This absorption current makes itself evident in the appreciable power factor displayed when a-c bridge measurements are made. It is also evident in the slow "soaking up" of charge after a direct potential is applied, often being measurable after some 15 min.

If the dielectric is a homogeneous material the charge due to absorption will be, after the potential has been impressed some time, evenly distributed throughout the mass. Assuming the charge to flow in from both electrodes during the period of absorption, the current flowing at the center of the dielectric will be zero and will increase as a linear function of the distance from the center of the material. From this analysis it is evident that the gradient is not constant during the absorption time but is a maximum at the electrodes and zero at the center of the dielectric. It is, however, probably constant after the charging process has ceased. Thus the required condition for a uniform voltage distribution in the insulation is not fulfilled and consequently the gradient over the surface cannot be uniform. If the gradient along the surface of the rubber cylinder anywhere exceeds the breakdown strength of the air small arcs will bridge the high gradient area. These small arcs are sufficient to ionize the air and cause complete breakdown of the gap

However, if the potential could be raised very gradually, or, in other words, the absorption current limited, it will be possible to increase the potential difference across the gap to a higher value than if the absorption current were allowed to create gradients near the electrodes in excess of the critical gradient of the air. To verify this point the following test was set up: Three samples were made in accordance with the specifications established by Mr. Maxstadt and were found to impart to the gap a breakdown strength of approximately 14.5 kv at 60 cycles per second. When a direct potential of 15 kv from a high voltage battery was applied the gap immediately broke down. Next a 10-megohm resistor was placed in series with the line and a large high voltage condenser connected in parallel with the gap. The voltage across the gap was thus caused to rise very slowly when potential was applied. Under this condition no breakdown occurred at 15 kv. Thus the gradients at the electrodes were held below the breakdown gradient.

This is probably the explanation of why rubber, a high loss dielectric, or one showing a comparatively large absorption current will cause a gap to break down while glass or other low loss dielectrics will not under the same potential conditions.

Very truly yours,

Eric A. Walker
(Electrical Engineering Department, Tufts College, Medford, Mass.)

## Graphical Solution of Star-Delta Transformations

*To the Editor:*

I read with interest the letter "Graphical Solution of Delta-Star Resistance Transformations" by W. W. Edson which you published in the October 1934 issue of Electrical Engineering, p. 1427.

In connection with the solution of equivalent delta-wye impedances (having the same ratio of resistance to reactance) your readers may be interested to know that an equivalent delta impedance may be found from known wye impedances by means of the simple diagram shown in Fig. 1. In this diagram $A$, $B$, and $C$ are the delta impedances, and $a$, $b$, and $c$ are the wye impedances. The equivalent delta impedances in terms of the wye impedances are as follows:

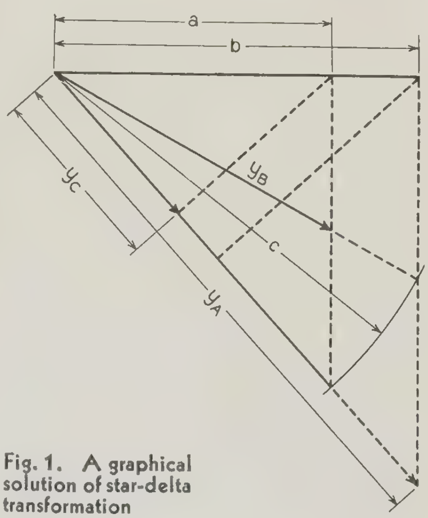



**Fig. 1. A graphical solution of star-delta transformation**

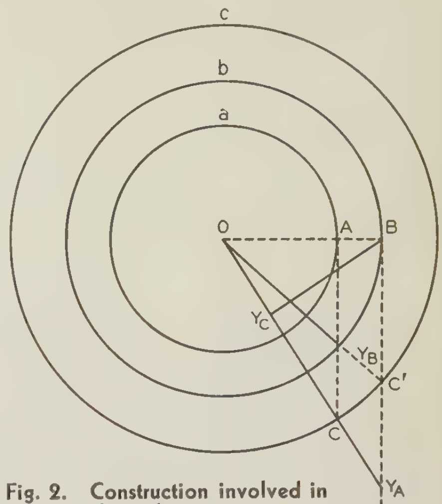



**Fig. 2. Construction involved in method of transformation**

$a = OA \quad b = OB \quad c = OC$
$y_A = OY_A \quad y_B = OY_B \quad y_C = OY_C$

$$A = b + c + y_A$$
$$B = a + c + y_B$$
$$C = a + b + y_C$$

As a matter of interest the construction and proof of this method follow.

### Procedure

The procedure for this method (see figure 2) is as follows:

1. Let the smallest wye impedance be represented by $a$. Let the intermediate value of the 3 wye impedances be represented by $b$, and the largest wye impedance by $c$.

2. With $a$, $b$, and $c$ as radii draw 3 concentric circles.

3. Draw line $OB$ containing $OA$ (radius of $a$) and $OB$ (radius of $b$).

4. At points $A$ and $B$ draw tangents to circles $a$ and $b$.

5. These tangents intersect circle $c$ at $C$ and $C'$, respectively.

6. $Y_A$ is the intersection of $OC$ extended and tangent at $B$. Then if $OY_A$ is denoted by $y_A$, the equivalent delta impedance $A = b + c + y_A$.

7. $Y_B$ is the intersection of $OC'$ and the tangent at $A$. Then if $OY_B$ is denoted by $y_B$, the equivalent delta impedance $B = a + c + y_B$.

8. $Y_C$ is the intersection of a normal to $OC$ from point $B$ and the line $OC$. Then if the intercept $OY_C$ is denoted by $y_C$, the equivalent delta impedance $C = a + b + y_C$.

### Proof

The well-known relationship between the equivalent delta impedance and the known wye impedance is:

$$A = \frac{ab + ac + bc}{a}$$

From similar triangles $OY_AB$ and $OCA$

$$\frac{y_A}{c} = \frac{b}{a} \qquad y_A = \frac{bc}{a}$$

Therefore $A = b + c + y_A = b + c + \frac{bc}{a} = \frac{ab + ac + bc}{a}$

From similar triangles $OY_BA$ and $OC'B$

$$\frac{y_B}{c} = \frac{a}{b} \qquad y_B = \frac{ac}{b}$$

Therefore $B = a + c + y_B = a + c + \frac{ac}{b} = \frac{ab + bc + ac}{b}$

From similar triangles $OY_CB$ and $OY_AB$

$$\frac{y_C}{b} = \frac{b}{y_A} \qquad y_C = \frac{bb}{y_A} = \frac{bb}{\frac{bc}{a}} = \frac{ab}{c}$$

Therefore $C = a + b + y_C = a + b + \frac{ab}{c} = \frac{ac + bc + ab}{c}$

Very truly yours,

David J. Ball (Enrolled Student)
(Rensselaer Polytechnic Institute,
Troy, N. Y.)

## Operational Calculus

*To the Editor:*

This communication proposes to correct a number of the inaccuracies in Prof. M. F. Gardner's paper "Operational Calculus" appearing in the October 1934 issue of Electrical Engineering, page 1,339–47.

When it is said that "operational calculus applies to systems or situations where cause and effect stand in linear relation," one should not infer that it is inapplicable to nonlinear conditions.

The extent to which an operator may be handled as an algebraic quantity is restricted by and determined from its definition. An operator may be handled as a quantity in ways other than that suggested by the technique of the ordinary algebra; *e. g.*, "Introduction to a Form of General Analysis," by E. H. Moore, New Haven Mathematical Colloquium, 1906; "A New Foundation for General Algebra," by J. W. Young, *Annals of Mathematics*, 1927, series 2, volume 29, page 47.

When Leibniz adopted the $\frac{d}{dx}$ form in 1675, Johann Bernoulli was already using the $D$ form.

The expansion of rational functions into terms having linear denominators was accomplished by L. Euler in 1775 ("Op. Anal.," volume 1, page 157), and by J. L. Lagrange in his formula for interpolation in 1795 ("Oeuvres," volume 7, page 286).

The determination of particular integrals by the method of partial fractions with the variable replaced by the operator $D$ seems to have been first published by R. Lobatto in his "Théorie des Charactéristiques" in 1837.

Between 1840 and 1880, operation methods were considerably researched upon by C. Babbage, G. Boole, J. Blissard, J. Hammond, C. J. Hargreave, J. Herschel, H. M. Jeffery, E. McClintock, I. Todhunter, and others. For a comprehensive survey of work done, see a paper by S. Pincherle in "Encyklopaedie der Mathematische Wissenschaften," band 2, teil 1, page 761. The so-called "shift" theorem:

$$\psi(D)\epsilon^{ht}\phi(t) = \epsilon^{ht}\psi(D + h)\phi(t)$$

may for instance be found in a paper by C. J. Hargreave (*Philosophical Transactions*, Royal Society, London, 1848, page 31) where it is stated to have been already well known.

The formula evaluation of coefficients in expansions even more general than that of Heaviside's (1886) was provided by G. Mittag-Leffler in 1880 (*q. v.*, "Modern Analysis" by E. T. Whittaker and G. N. Watson, 4th edition, page 134).

The essential and distinguishing features of Heaviside's $p$ operational calculus from the conventional $D$ operational calculus lie in the $p$-integration:

$$p^{-1}\{\phi(t)\mathbf{1}(_t)\} = \operatorname*{Lim}_{n \gtrless 0} \int_n^t \phi(t)\mathbf{1}(_t)dt$$

(*q. v.*, "Treatise on Differential Equations" by A. R. Forsyth, page 57. "Electromagnetic Theory" by O. Heaviside, volume 1, page 392; volume 2, paragraph 239, page 59) and in the introduction of the unit function:

$$\mathbf{1}(_t) = 0,\ 1 \text{ as } t\ 0 \lessgtr$$

into the operand so as to avoid getting any but desirable answers when the ordinary $D$ operational formulas are applied, with $D$ replaced by $p$, and $p^{-1}$ interpreted as the definite integral above.

Although Heaviside was well versed in Fourier analysis ("Théorie Analytique de la Chaleur" by J. B. J. Fourier, 1822; complex variable elaboration, by Cauchy, Dirichlet, Dini, etc.), no explicit evaluation of the unit function appears in his writings. The honor of determining the necessary and sufficient conditions under which this can be done falls to T. J. I.'A. Bromwich (London Mathematical Society *Proceedings*, volume 15, 1916; page 401; paper read Mar. 12, 1914):

$$\mathbf{1}_{(t)} = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} \frac{\epsilon^{\nu t}}{\nu}\, d\nu\ ,\ c > c_0 > 0$$

Hence, if:

$$\frac{Z\ (p)}{Y\ (p)}\, i_{(t)} = \phi\ (t)\ \mathbf{1}\ (_t)$$

and $i_{(t)} = 0$ for $t < 0$, then:

$$i_{(t)} = \frac{Y\ (p)}{Z\ (p)}\, \phi(t)\mathbf{1}(_t)$$

Utilizing the $D$ operational theorems:

$$\epsilon^{hD}F(t) = F(t + h)$$

$$\phi_0(D)\{\phi_1(t)\phi_2(t)\} = \phi_1(t + D_0)\phi_0(D_2)\phi_2(t)$$

and the explicit form of the unit function,

$$i_{(t)} = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} \left[\phi(t+D_\nu)\,\frac{Y(\nu)}{Z\,(\nu)}\right]\frac{\epsilon^{\nu t}}{\nu}\, d\nu$$

which is the contour integral solution of the Heaviside problem as substantially given by Bromwich, and his disciple, H. Jeffreys.

From the researches of Euler, as pointed out by Heaviside ("Electromagnetic Theory," volume 3, paragraph 526):

$$\frac{1}{p}\, f\,(t) = \int_0^\infty \epsilon^{-px} f\,(x)dx = \int_0^t f\,(x)dx$$

Hence obviously:

$$\frac{Y(p)}{pZ(p)}\,\phi(t)\mathbf{1}(_t) = \int_0^\infty i_{(t)}\epsilon^{-pt}dt$$

Thus, the so-called "Carson" integral equation (*Bell System Technical Journal*, Nov. 1922, page 43) was known to Heaviside at least before 1912. Why more extended use of this integral equation was not made by Heaviside is recognizable, first, because of his brilliant success in solving difficult problems by closed and open operational methods, and secondly, by finishing the half-quotation ("Electromagnetic Theory," 1899, volume 2, page 11) in J. R. Carson's book ("Electric Circuit Theory and the Operational Calculus," 1926, page 32).

"... are apt to take refuge in a definite integral, and call that the solution. It is certainly one form of the solution. But it may be just as hard, or harder, to interpret than the differential equation of the problem in question."

That the Heaviside-Carson integral equation is now meeting applicational success is because admittedly "a large number of infinite integrals of the type appearing in equation 9 have been worked out" (Carson, *Bell System Technical Journal*, Nov. 1922, page 48); equation 9 in the paper being that in question.

Although not entirely novel, the transform technique evolved in van der Pol's papers (1929 on) is very useful. Such technique has its purest form in symbolic analysis; *q. v.*, "Principia Mathematica" by A. N. Whitehead and B. Russell.

Very truly yours,

I. H. Barkey (A'29)
(Technical Consultant, 2020 32nd St.,
Brooklyn, N. Y.)

## Wine Makers and Bottle Makers—A Parable

[Editor's Note: The parable which follows was part of a discussion by Professor Karapetoff of President J. Allen Johnson's address "An Insight Into the Workings of the Institute," both of which were presented at the A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, 1934. President Johnson's address was published in Electrical Engineering for July 1934, p. 1039–46. In Professor Karapetoff's parable which follows, the specialists in any field are compared to the "wine makers," and the administrators in the same field are compared to the "bottle makers." In the Institute's organization, both "wine makers" and "bottle makers" will be found.]

*To the Editor:*

A certain country was noted for its wonderful native wines, both sparkling and mellow. Grapes were grown by small individual owners, and each specialist was proud of his product and of its distinct taste. For fermentation and aging, wine was poured into various casks, skins, bottles, jugs, etc., as the case might be. From time to time there was some talk about the containers being not always satisfactory and certainly not uniform. Gradually the makers of bottles and jugs organized an association to improve and to standardize their products, so as to provide the wine makers with better containers and thereby to assist them both in the production and marketing of the wines.

It so happened that while it was easy for bottle makers to become organized (their product being standard and comparatively easy to manufacture), the wine makers continued their individual production, at least for the choicest vintages, where intimate individual knowledge, skill, and professional pride were important factors. As

time went on, there was more and more talk about excellent bottles and less and less talk about the wines themselves, because the organized bottle makers had better publicity channels. In some cases fancy mass-production bottles began to be used for mediocre wines, thus discouraging the best viniculturists.

To make the situation worse, the bottle makers conducted their activities as part of the wine making industry, and the wine makers were only invited from time to time as a favor to sit with them in their discussions. To make the camouflage complete, the bottle makers adopted for themselves the honorary degrees which the wine makers originally used to bestow upon their own distinguished confreres, such as master of fizz and doctor of fermentation, although the recipients from among the bottle makers did not even understand the meaning of the words. Every time an intricate technical problem in wine making arose, the bottle makers appointed an elaborate committee of their own men, with the final result that a bottle of a somewhat different shape was recommended as a remedy, even though the difficulty may have been of chemical or bacteriological nature.

The bottle makers' association grew and prospered. Not satisfied with bottles for wine, the association appointed representatives to sit on joint committees with makers of other kinds of containers, such as bathtubs and garbage cans, it being assumed that they had much in common. In the meantime less and less of exquisite rare wines began to be produced, and more and more of "vin ordinaire" of uniformly sour taste, sold in various fancy bottles. Finally the more discerning consumers from abroad ceased buying wine from this particular country, and warehouses became filled with empty bottles of all kinds of fancy shapes. Some of the wine growers went into other pursuits, some continued outside the association, and some began forming small professional circles of their own, very simple in external form, and devoted exclusively to real improvements in the quality of wines and general theory of grape culture and fermentation. Full membership was restricted to actual grape growers and wine makers; anyone interested as an amateur could become an associate member, but bottle makers were strictly excluded. In some circles, to be admitted one even had to prove that neither of his grandfathers was a bottle maker nor related to one.

In the end the cycle was completed and the wine growers again acquired the prominence due them, while the bottle makers' association became too top-heavy to continue to exist. Individual bottle makers found their proper modest function furnishing simple reliable bottles as specified by the wine makers. From the temporary flare-up, when the bottle makers came near ruining the wine industry by their overzealousness and naive conceit, some of the puzzling old sayings originated, such as, "tell your troubles to the bottle makers," or "try a different-shape bottle."

Very truly yours,

VLADIMIR KARAPETOFF
(A'03, F'12, and Life Member)
(Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.)

## Designations of Photo-Electric Devices

*To the Editor:*

Attention should be drawn to the desirability of standardizing the designations of the 4 distinct classes of photo-electric devices. There are:

1. The vacuum-tube alkali-metal cells which operate with an external source of electromotive force. These are commonly referred to as photo-electric cells or as photo cells, alternatively as photo-electric tubes or photo tubes. These names are well understood.

2. The cells which change their resistance under the influence of light. These are well called photo-resistance or photo-conductance cells.

3. The cells containing an electrolyte and operating in connection with some voltaic action. These are photovoltaic cells.

4. The oxide-on-metal cells which without any external electromotive force furnish a current proportional to the incident luminous flux. These are variously called blocking-layer cells, barrier-layer cells, and barrage cells. These terms are objectionable in that they represent the selection of a name in accordance with a theory of the operation of the device rather than from a consideration of its obviously distinctive properties. They are also called photo-voltaic cells which is clearly a misnomer.

There is clearly a need for giving to this last class of cells a name which is both distinctive and descriptive. The most distinctive feature of these cells is that they will deliver a current proportional to luminous flux without the application of an external electromotive force. True, this is also true of the photo-voltaic cells, but they already have a distinctive name of their own and there is no chance for confusion. The oxide-on-metal cells constitute the only practical photo-electric devices in which the electromotive force necessary to produce the current is generated in the cell itself, under the influence of light. These cells therefore might be called "photo-emf" cells.

The presence of a true electromotive force in these cells has been questioned. This matter may be examined in the light of the following definition contained in the report on definitions of electrical terms of the sectional committee which the A.I.E.E. is sponsoring: "Electromotive force is the property of a physical device which tends to produce an electric current in a circuit." The answer is unambiguous. The question as to the allowability of forming a word partly out of an abbreviation will have to be answered by saying that the word so formed is understandable, practical, convenient and fits the case. It is an innovation, but engineers and scientists are usually not afraid of justifiable innovations.

At any rate there is need for a good name, whether it be this one or another, and it should be given and sanctioned before any of the present unsatisfactory terms becomes so firmly entrenched as to remain a burden on terminology for all time.

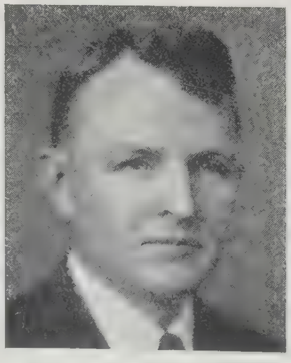
Very truly yours,

CLAYTON H. SHARP
(A'02, F'12, and member for life)
(Technical Consultant in Electricity and Light, White Plains, N. Y.)

# Personal Items

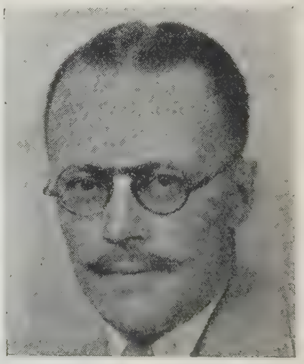
W. R. SMITH (M'18, F'30) assistant chief engineer, United Engineers and Constructors, Inc., Newark, N. J., has been appointed chairman of the board of examiners of the Institute for the year 1934–35. Mr. Smith was born at Charleston, S. C., in 1885. In 1906 he graduated from Clemson Agricultural and Mechanical College, receiving the degree of B.S. in mechanical and electrical engineering. Following graduation he remained for a year as secretary and engineering assistant to the department head and then entered the apprentice course of the Westinghouse Electric and Manufacturing Company. From 1908 to 1913 he was employed by the Hartford Suspension Company, Jersey City, N. J., and from 1914 to 1922 by the Public Service Electric Company, Newark, N. J., where he was concerned with construction work, becoming field engineer in 1917. With the formation of the Public Service Production Company in 1922 he became superintendent of the electrical construction department and managing electrical engineer in charge of the electrical engineering department in 1924, accepting his present position in 1927. He has been a member of the board of examiners of the Institute since 1930, and is chairman of the New York Section. His

W. R. SMITH



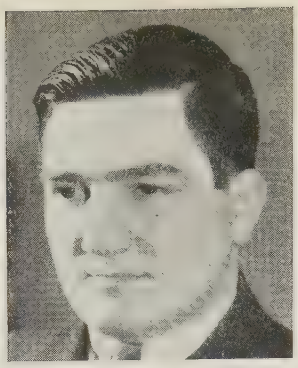
E. L. MORELAND

A. A. KRONEBERG



HAROLD GOODWIN, JR.

F. D. KNIGHT



M. K. GOLDSTEIN

other memberships include the Illuminating Engineering Society, the Edison Electric Institute, and the Essex Electrical League.

E. L. Moreland (A'11, F'21) of Jackson and Moreland, Boston, Mass., has been appointed chairman of the standards committee of the Institute for the year 1934–35. Mr. Moreland was born at Lexington, Va., and in 1905 graduated from The Johns Hopkins University, Baltimore, Md., with the degree of A.B. in mathematics and physics. Three years later he entered the employ of D. C. Jackson (A'87, F'12, and past-president) and W. B. Jackson (A'97, F'13) consulting engineers in Chicago, Ill., and Boston, Mass. He was made a partner of the firm in 1916. Upon his return from military service after the war the partnership with D. C. Jackson was formed. Among the projects of this firm have been the electrification of the Great Northern Railway through the Cascades and the electrification of the Lackawanna Railroad suburban service out of Hoboken, N. J. Mr. Moreland has been a member of the Institute's transportation committee since 1931, and of the standards committee since 1932. He has also served on the committees on power generation, 1929–31; electrical machinery, 1929–31; technical program, 1929–34; and Institute policy, 1933–34; and has recently been appointed Institute representative on the standards council of the American Standards Association.

Harold Goodwin, Jr. (A'11, F'23) consulting engineer, Wyncote, Pa., has been appointed chairman of the Institute's committee on transfers for the year 1934–35. Mr. Goodwin was born at Philadelphia, Pa., in 1888. In 1908 he received the degree of B.S. in electrical engineering from the University of Pennsylvania, and entered the employ of the Philadelphia Electric Company. He became superintendent of distribution in 1915, in which position he devised the 4-phase 2,300/4,600-volt system of distribution. In 1919 he entered power and transmission work with the General Electric Company, Schenectady, N. Y., and the following year became engaged in a power survey which was under the auspices of the U.S. Geological Survey. In 1922 he joined the staff of the engineering firm of Sanderson and Porter, New York, N. Y., and subsequently was connected with the Columbia Engineering and Management corporation. He now has offices in Philadelphia, Pa., and is associated with H. L. Doherty and Company, New York. He has served on the Institute's committees on membership, 1916–18; standards, 1923–25; electrical machinery, 1924–27; and associate dues and related matters, 1932–34. He has been a member of the board of examiners since 1925 and was chairman 1931–34, and has been a member of the committee on transfers since 1932.

F. D. Knight (M'25) assistant superintendent, generating department, Edison Electric Illuminating Company of Boston, Mass., has been appointed chairman of the safety codes committee of the Institute for the year 1934–35. Mr. Knight was born at Limerick, Maine, in 1883. After a few years' experience with the General Electric Company at Lynn, Mass., he entered the University of Maine and received the degree of B.S. in electrical engineering in 1909. For 16 years he was connected with Stone and Webster, Inc., in enterprises in various parts of the country. Among these were the pioneer mercury turbine plant of the Hartford Electric Light Company and the first 1,400-lb steam plant of the Edison Electric Illuminating Company of Boston. Mr. Knight assumed his present duties with the latter company in 1925. He has been a member of the safety codes committee of the Institute since 1930, and is also Institute representative on the committee on low voltage hazards of the National Safety Council, on the electrical committee of the National Fire Protective Association, and on the National Fire Waste Council.

M. K. Goldstein (A'33) development engineer, J. D. Radio Company, Baltimore, Md., has been awarded the 1933 A.I.E.E. Middle Eastern District prize for best paper for his paper "Telemetering in Large Power Stations." Mr. Goldstein was born at Baltimore in 1909, and is a graduate of The Johns Hopkins University, class of 1930. He continued his studies with the aid of a scholarship and received the degree of doctor of engineering in 1933. He majored particularly in radio engineering, engaging in research on development, construction, and studies of duplex triple-grid tubes with particular reference to their intergroup shielding factors and effects of space charge modifications. During summers he has been employed as expert examiner in mathematics by the United States Government, and by the J. D. Radio Company. In 1933 he made an extensive survey of telemetering apparatus with particular reference to its use of thermionic and photronic devices upon which his paper was based. He is a member of the Institute of Radio Conferees, Institute of Radio Engineers, and Sigma Xi.

A. A. Kroneberg (A'26) technical assistant to operating engineer, Southern California Edison Company, Ltd., Los Angeles, with his co-author L. F. Hunt (A'21) has been awarded the 1933 A.I.E.E. Pacific District prize for best paper for their paper entitled "Some Recent Relay Developments." Mr. Kroneberg was born at Ekaterinbourg, Russia, in 1899. He was educated at schools in Russia and after coming to the United States in 1923 entered the electrical engineering course at California Institute of Technology, where he was elected to Tau Beta Pi. Following graduation in 1926 he entered the training course of the Southern California Edison Company and became electrician at the Long Beach steam station. He was appointed to his present position in 1931.

L. F. Hunt (A'21) technical assistant to the operating engineer, Southern California Edison Company, Ltd., Los Angeles, has, with his co-author, A. A. Kroneberg (A'26) been awarded the 1933 best paper prize of the Institute's Pacific District for the paper entitled "Some Recent Relay Developments." He was born in San José, Calif., in 1897. In 1919 he graduated from the University of Southern California with the degree of bachelor of science in electrical engineering. In 1928 he received the degree of electrical engineer from this institution. During the period 1916–19 he was electrician in charge for the University of Southern California, and in 1919 entered the graduate student course of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. The following year he became a member of the supply engineering department of this company, engaged in relay design and application, continuing this work until 1922 when he undertook protection engineering for the Southern California Edison Company. In 1924 he became assistant to the chief electrical engineer of the company, and the following year became development engineer and technical assistant to the research engineer. Since 1930 he has been technical assistant to the operating engineer. He has designed many relays and relay schemes, the most recent of which is a carrier current system. He has also designed many high speed recording instruments. He is a member of Eta Kappa Nu and Sigma Alpha Epsilon fraternities.

S. W. Hannah (Enrolled Student) service department, Hoover Company, Denver, Colo., with his co-author A. E. Logan (Enrolled Student) has been awarded the Institute's 1933 North Central District prize for Branch paper and has received honorable mention in the 1933 national awards for Branch paper for the paper entitled "The Measurement and Control of the Synchronous Machine Torque Angle." He was

born at Denver, March 30, 1911, and entered the University of Colorado at Boulder in 1929 as a holder of a scholarship. During his senior year, when the paper was presented, he was chairman of the Institute's University of Colorado Branch. In 1933 he received the degree of bachelor of science in electrical engineering with special honors, and received a fellowship in the department of electrical engineering for the year 1933–34. Mr. Hannah received the degree of master of science in 1934. He is a member of Tau Beta Pi, Sigma Tau, Sigma Xi, and Eta Kappa Nu.

Arthur Simon (A'03, F'13) engineering and patent consultant, Milwaukee, Wis., has had the honorary degree of doctor of science conferred upon him by Marquette University, Milwaukee. The citation stated "Arthur Simon—patent expert for Cutler-Hammer Co., in whose services he has been for 30 years—a citizen who has generously given his technical services to the public welfare, who by his own contributions to the science of electrical engineering—by his papers before local and national engineering societies, and by his service to the engineering profession, locally, nationally, and internationally, is entitled to the degree of doctor of science, honoris causa." Dr. Simon was a member of the Institute's committee on power transmission and distribution, 1923–25.

H. H. Barnes, Jr. (A'00, F'13) commercial vice president, General Electric Company, New York, N. Y., is serving as assistant chairman of the electrical section of a committee of business men in a drive to increase the membership of The Merchants' Association of New York. Mr. Barnes has been very active in committee work in the Institute, and is now serving on the Edison medal committee and on the committee on code of principles of professional conduct. He was a manager of the Institute 1910–13, and a vice president 1913–15.

E. C. M. Stahl (M'27) formerly assistant operating superintendent, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been appointed operating superintendent. Mr. Stahl is a graduate of Cornell University, and was with the New York Central Railroad and the Pittsburgh Transformer Company before joining the Brooklyn Edison Company 12 years ago. He became assistant operating superintendent in 1930.

P. H. Moon (A'24, F'34) assistant professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, has designed and will be in charge of a 4-year course in illuminating engineering to be given at that college. Professor Moon was a member of the Institute's committee on the production and application of light 1931–33.

Frederick Creedy (M'30) formerly research assistant professor at Lehigh University, Bethlehem, Pa., has accepted an appointment as professor of electrical engineering at the University of British Columbia, Vancouver, Canada. Professor Creedy is a member of the Institute's committee on electric welding, on which he has served since 1930.

Victor Frederiksen (A'32) is electrical engineer for the National Electric Coil Company, Columbus, Ohio. This company was formerly the National Armature and Electric Works, Bluefield, W. Va., where Mr. Frederiksen has been located since 1926, and which, while continuing there is opening a new plant at Columbus.

Abram Hussey (A'06, M'18) superintendent of distribution, Brooklyn Edison Company, Inc., Brooklyn, N. Y., for more than 21 years, retired recently. Before coming to the Brooklyn Edison Company he was employed by the New York Central Railroad in connection with the electrification in the New York area.

C. W. Caldwell (A'32) formerly in the electrical engineering department of the University of South Dakota, Vermillion, has become instructor in electrical measurements at Purdue University, Lafayette, Ind. Mr. Caldwell has been serving as counselor of the University of South Dakota Branch of the Institute.

Paul Doty (A'04, M'12) formerly chairman of the Minnesota State Board of Registration, St. Paul, has been appointed regional reconditioning supervisor, Home Owners Loan Corporation, Atlanta, Ga. Mr. Doty is president of The American Society of Mechanical Engineers and a vice president of American Engineering Council.

T. R. Langan (A'13, M'30) northeastern district manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., is a member of the electrical section of a committee of business men in a drive to increase the membership of The Merchants' Association of New York.

L. B. Bender (A'20, M'27) signal corps, U.S. Army, has been promoted from major to lieutenant colonel, and has been transferred from headquarters, fifth corps area, Columbus, Ohio, to Wright Field, Dayton, for duty in charge of the aircraft radio laboratory.

R. A. Belinge (A'28) valuation engineer, San Francisco, Calif., is with the United States Forest Service. He was formerly chief engineer, East Bay Cities Rate Department, Oakland, Calif., and has the rank of captain, signal reserve, United States Army.

Kiyosho Yamamoto (A'20) formerly director in charge of the manufacturing department, Sumitomo Electric Wire and Cable Works, Ltd., Osaka, Japan, has become managing director of the Sumitomo Aluminum Reduction Company, Ltd., Niihamacho, Niigun, Ehimeken, Japan.

L. J. Montgomery (A'18) who has been assistant general sales manager of the New York and Queens Electric Light and Power Company, Long Island City, N. Y., since 1917, has been appointed general sales manager.

M. O. DellPlain (A'08, M'12) president of the Northern Indiana Public Service Company, Hammond, Ind., since 1929, has resigned to become vice president of the Welsbach Street Light Company of America, Philadelphia, Pa.

I. A. Patten (A'28) assistant general superintendent of the Lynn Gas and Electric Company, Lynn, Mass., since 1930, has been appointed general superintendent. He has been with the Lynn company since 1911.

W. R. Streuli (A'27) until recently with the substation department of the Long Island Railroad, Long Island City, N. Y., has joined the staff in charge of design and development of the Telephonwerke Albisrieden, Zurich, Switzerland.

E. R. McKee (A'30) who has been assistant professor of electrical engineering at Iowa State College, Ames, has accepted a position as professor and head of electrical engineering at the University of Vermont, Burlington.

J. D. Stacy (A'20) who was formerly in charge of the radio receiver division of the RCA-Victor Company at Camden, N. J., has accepted a position as capacitor design engineer for the General Electric Company at Pittsfield, Mass.

E. G. Cullwick (A'26, M'33) formerly assistant professor of electrical engineering, University of British Columbia, Vancouver, Canada, is now in the electrical engineering branch of the Military College of Science, London, England.

E. C. Milde (A'32) formerly an instructor in physics at Worcester Polytechnic Institute, Worcester, Mass., has accepted a position in the laboratories of the Atwater Kent Manufacturing Company, Philadelphia, Pa.

C. M. Underwood (A'31) formerly sales engineer, Raytheon Manufacturing Company, Newton, Mass., is senior welding engineer, United States Navy Yard, Washington, D. C.

C. H. Lydall (A'20) formerly representative in Chicago, Ill., of Merz and McLellan, London, England, is now North American representative with offices in London.

C. W. Dalzell (A'27) formerly a sales engineer for the Suburban Electric Development Company, Pittsburgh, Pa., is now with the Heyer Products Company, Inc., Belleville, N. J.

L. S. Cooper (A'29) formerly with the Hoffman Beverage Company, Newark, N. J., is an engineering assistant in the transportation department of the General Electric Company at Erie, Pa.

W. A. Black (A'12, M'30) formerly district manager, Allen-Bradley Company, Cleveland, Ohio, is electrical sales manager for the Fairbanks Morse Company, Cincinnati, Ohio.

James Dixon (A'02, M'13) formerly with the Reliance Electric and Engineering Company, Cleveland, Ohio, is now with the Crocker Wheeler Electric Manufacturing Company, Ampere, N. J.

C. D. Friday (A'30) who has been a post-graduate student at Ohio State University, Columbus, is assistant electrical engineer, bureau of yards and docks, Navy Department, Washington, D. C.

K. D. Engle (A'25) formerly with the Cornell-Dubilier Corporation, New York, N. Y., is now factory superintendent for the Micamold Radio Corporation, Brooklyn, N. Y.

Gordon Cavanagh (A'32) valuation and rate engineer who was with the North American Light and Power Company, Chicago, Ill., is now with the Illinois Power and Light Corporation, Monticello, Ill.

E. B. Heath (A'25) formerly of Pacific Palisades, Calif., has accepted a position in the department of engineering and mathematics of the San Bernardino Valley Junior College, San Bernardino, Calif.

J. R. Strong (A'01 and member for life) president, Tucker Electrical Construction Company, New York, N. Y., has retired from business and resides at Short Hills, N. J.

A. R. Nelson (A'22, M'29) Public Service Electric and Gas Company, Newark, N. J., has been appointed assistant superintendent of electrical distribution in the Essex County division of the company.

F. S. Kingston (M'30) Elizabeth, N. J., is president of the recently organized Kingston-Conley Electric Company of Jersey City, N. J., manufacturers of fractional horsepower motors.

P. W. Baker (A'16, M'29) formerly engineer in the small motor division, Wagner Electric Company, St. Louis, Mo., is now in the engineering department of the Kelvinator Corporation, Detroit, Mich.

M. F. Beall (A'32) Grand Rapids, Mich., is assistant to the chief engineer, Michigan Gas and Electric and Michigan Public Service companies, with general offices at Holland, Mich.

W. W. Woodruff (A'16) Swarthmore, Pa., is engineer of design and construction, Tennessee Valley Authority, and is now located at Chattanooga, Tenn.

Nathaniel Bishop (A'26) Bridgeport, Conn., has joined the radio sales engineering department of the General Electric Company in Bridgeport.

D. C. Green (M'26) president, Middle West Utilities Company, Chicago, Ill., has been named a temporary trustee of the company, which is in receivership.

F. M. Tait (A'94, F'12) president, Dayton Power and Light Company, Dayton, Ohio, has been elected a director of the Columbia Gas and Electric Corporation.

L. V. Banta (A'34) Bloomfield, N. J., is assistant to the sales engineer, Edison storage battery division of Thomas A. Edison Inc., West Orange, N. J.

C. M. Wolfe (A'27) formerly of Kingwood, W. Va., is now at the New Mexico State College of Agriculture and Mechanic Arts, State College.

C. F. King, Jr. (A'16) general engineer, Westinghouse Electric and Manufacturing Company, has been transferred from East Pittsburgh, Pa., to Philadelphia, Pa.

J. E. Davies (A'32) distribution engineer, Public Service Company of Colorado, has been transferred from Idaho Springs to Denver.

H. R. McKinney (A'33) U. S. Electrical Manufacturing Company, Los Angeles, Calif., has been transferred from the engineering to the sales department.

J. M. Lyons (A'28) assistant engineer, General Electric Company, has been transferred from West Lynn, Mass., to Schenectady, N. Y.

O. R. Fitz (A'33) Bayside, N. Y., is an engineering assistant with the New York and Queens Electric Light and Power Company, Flushing, N. Y.

M. W. Smedburg (A'33) formerly employed by the board of public utilities, Jamestown, N. Y., is working for the Tennessee Valley Authority, Knoxville, Tenn.

D. W. Yambert (A'16, M'21) is an engineer with the Dravo Contracting Company, Pittsburgh, Pa., and resides at Ada, Ohio.

C. M. Tolman (A'20, M'20) is an engineer with the Bartlett Hayward Company, New York, N. Y., and resides in Brooklyn, N. Y.

H. W. Morris (M'24) Washington, D. C., is with the bureau of public debt, accounts and audits, U.S. treasury department.

C. R. Shields (A'34) is a hydroelectric plant operator for the Western Colorado Power Company at Telluride.

J. T. Kelly, Jr. (A'12, M'22) St. Louis, Mo., is a salesman for the General Electric Company there.

# Obituary

Frank Julian Sprague (A'87, M'97, F'12, HM'32, past-president and member for life) president, Sprague Safety Control and Signal Corporation, New York, N. Y., died October 25, 1934. Doctor Sprague was born at Milford, Conn., July 25, 1857. From 1874 to 1878 he attended the U. S. Naval Academy, and in 1882 attended the Crystal Palace Exhibition, London, to prepare a report for the Navy Department on electrical machinery, in which he recommended the use of direct-connected compound-wound dynamos for use on ships. In the spring of 1883 he resigned from the navy and for a year worked with Thomas A. Edison. The Sprague Electric Railway and Motor Company was organized by him in 1884, and in 1887 he undertook the building of the first extensive electric street railway, at Richmond, Va., on a 90-day contract. His success here led to contracts for 110 other railways. This company was merged with the General Electric Company in 1890, and in 1892 Doctor Sprague formed the Sprague Electric Elevator Company for the development and promotion of electric elevators. In 1895 he invented the multiple unit system of train control, which was applied 2 years later on the elevated lines in Chicago, Ill., for which project the Sprague Electric Company was formed. From 1903 to 1908 he served on the commission for the electrification of the Grand Central Terminal, New York. His automatic train control system was developed in 1906, at which time he formed the Sprague Safety Control and Signal Corporation. Doctor Sprague is credited with a number of other accomplishments, including the introduction of the constant speed motor, regenerative control, 3-point geared motor suspension, and, in 1926, the dual elevator, whereby 2 elevators operate in the same shaft. Doctor Sprague received the Elliot Cresson medal of the Franklin Institute in 1904, the A.I.E.E. Edison Medal in 1910, and the Franklin medal of the Franklin Institute in 1921. Stevens Institute of Technology conferred upon him the degree of doctor of engineering, Columbia University that of doctor of science, and the University of Pennsylvania that of doctor of laws. In October 1934, the John Fritz gold medal, the highest distinction bestowed jointly by the national societies of civil, mining and metallurgical, mechanical, and electrical engineers of the United States, was unanimously awarded him, presentation to be made at one of the sessions of the Institute's winter convention; Doctor Sprague received notification of the award only a few days before his death. For the period 1890–92 he served the Institute as a vice president, and was president for 1892–93. The committees on which he served were the Edison medal, 1911–16, traction and transportation (now transportation), 1914–16, and a special committee on the history of the electrical industry, 1932–34. A paper on the early developments in electric transportation was prepared by Doctor Sprague for the May 1934 issue of Electrical Engineering, and was published on pages 695 to 706. A biographical sketch of Doctor Sprague was given on page 791 of the same issue.

Martin L. Roper (M'24) assistant to superintendent of transmission, Pennsylvania Power and Light Company, Hazleton, Pa., died April 22, 1934, according to word just received at Institute headquarters. He was born at Brooklyn, Pa., July 23, 1883, and received the degree of bachelor of science in electrical engineering at Pennsylvania State College in 1906. After short periods of time with the Westinghouse Electric and Manufacturing Company as an engineering apprentice and with the Allegheny County Light Company, Pittsburgh, Pa., as a draftsman, he entered the coal mining department of the Delaware, Lackawanna, and Western Railroad at Scranton, Pa., and subsequently became district electrical foreman, being transferred to Kingston, Pa., in 1912. In 1921 he undertook a similar position with the Glen Alden Coal Company there, and later that year became general electrical foreman for that company at Scranton. Since 1930 he had been with the utility. Mr. Roper was a vice chairman of the Lehigh Valley Section of the Institute during the year 1933–34.

Warren Partridge (A'04, M'29) vice president, Utility Management Corporation, New York, N. Y., died October 30, 1934. He was born at Boston, Mass., January 10, 1875. After graduation in 1897 from the electrical engineering course at Harvard University he was employed by the Public Service Corporation of New Jersey at Newark as an inspector, division superintendent, and assistant chief engineer, until in 1909 he became general superintendent for the Springfield Power and Light Company, Springfield, Ill. Three years later he assumed the office of general manager of the Pennsylvania Public Service Company, Clearfield. From 1919 to 1925 he was a consulting engineer for H. D. Walbridge and Company, New York, after which he was with the J. G. White Management Corporation, serving as vice president of the Pennsylvania Electric Company and subsidiaries and the New England Gas and Electric Corporation and subsidiaries. Mr. Partridge was appointed a vice president of the Utilities Management Corporation about 4 years ago.

Charles W. Parkhurst (A'01, F'13) consulting engineer, Berwind-White Coal Mining Company, Philadelphia, Pa., died September 30, 1934. He was born at Hammonton, N. J., July 5, 1870, and was a graduate of Lehigh University, class of 1893, receiving the degree of electrical engineer. He was first employed in the electrical department at Cramps Ship Yard, Philadelphia, where he became assistant superintendent and had charge of the electrical installation on several ships. In 1897 he installed electrical equipment for a Pennsylvania Railroad ferry at New York, N. Y., and later that year designed some fittings for the slot conduit of the Metropolitan Street Railways Company of that city. Following short periods in the employ of the Union Iron Works, San Francisco, Calif., and the Siemens and Halske Electric Company, Chicago, Ill., as a designer of electrical equipment he became electrical engineer and superintendent of the electrical department of the Cambria Steel Company, Johnstown, Pa., where he had charge of the engineering, installation, and operation of all electrical equipment. At this time he was also a consulting engineer for the Citizens Light, Heat, and Power Company of Johnstown and the Pennsylvania Iron Mining Company of Vulcan, Mich. Since 1917 he had been consulting engineer for Berwind-White Company, and also for 6 years for Perin and Marshall, New York. Mr. Parkhurst had been reappointed this year as a member of the Institute's committee on applications to mining work, on which he had served since 1931. He was a past-president of the Association of Iron and Steel Electrical Engineers, and a member of the American Electrochemical Society and Tau Beta Pi.

George Washington Atkinson (A'15, M'25) of Springfield, Mass., construction engineer, procurement division, public works branch, United States treasury department, died September 15, 1934. He was born at Morocco, Ind., March 19, 1883. In 1908 he received the degree of bachelor of science in electrical engineering from Purdue University, and the degree of electrical engineering in 1911. From 1909 to 1917 he was employed in the supervising architects office, treasury department, Washington, D. C., where he was concerned with mechanical and electrical equipment for federal buildings. For 4 years following 1917 he was in charge of all electrical equipment at the Springfield Armory, and then became superintendent of power and maintenance for the Gilbert and Barker Manufacturing Company, Springfield, for 10 years. During the last 3 years as construction engineer he had charge of the construction of the postoffices at Palmer and Easthampton, Mass. Mr. Atkinson was at one time chairman of the Springfield Section of the Institute.

John Hugh McManus (A'10) special utility representative, Johns-Manville Corporation, New York, N. Y., died October 7, 1934. He was born at New York, June 8, 1879. From 1897 to 1904 he was employed by the Westchester Lighting Company, Port Chester, N. Y., after which he studied at Ohio State University and Pratt Institute. For 3 years following 1906 he was employed by the New York and New Jersey Telephone Company, Newark, N. J., and then entered the Johns-Manville organization as an electrical salesman.

Gomer Louis Evans (M'21) vice president, Wagner Electric Company, St. Louis, Mo., died September 10, 1934. He was born at St. Louis, November, 26, 1885. Following his graduation from the electrical engineering course at Washington University he entered the production division of the Wagner Electric Company, of which he subsequently became superintendent of production, assistant vice president, and vice president.

# Membership

## Recommended for Transfer

The board of examiners, at its meeting held November 27, 1934, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

**To Grade of Fellow**

Campbell, Arthur B., chief engr., Seth Thomas Clock Co., Thomaston, Conn.
Coles, Edmund P., mgr., Gen. Elec. Co., Charlotte, N. C.

2 to Grade of Fellow

**To Grade of Member**

Bass, L. B., sales engr., Gen. Elec. Co., Oklahoma City, Okla.
Branson, Edward H., director of research labs., General Railway Signal Co., Rochester, N. Y.
Brown, Nelson E., asst. supt. of operation, Buffalo Gen. Elec. Co., Buffalo, N. Y.
Clark, Joseph, asst. engr., Brooklyn Edison Co., Brooklyn, N. Y.
Edwards, Manley W., elec. engr., Municipal Lt. & Pwr. Dept., Pasadena, Calif.
Foster, Clair V., proprietor and Mgr., North End Garage, Niagara Falls, N. Y.
Gillespie, Leigh R., telephone engr., Rochester Tel. Corp., Rochester, N. Y.
Gordon, Harry E., equipment engr., Rochester Tel. Corp., Rochester, N. Y.
Harper, Richard G., sales engr., Westinghouse E. & M. Co., Buffalo, N. Y.
Hazlett, H. M., supt. of production, Porto Rico Ry. Lt. & Pwr. Co., Santurce, Porto Rico.
Hopkins, Ralph A., sales engr., Westinghouse E. & M. Co., Los Angeles, Calif.
Hubbard, Horace S., designing engr., Gen. Elec. Co., Pittsfield, Mass.
Hull, R. H., asst. prof. of elec. engg., University of Idaho, Moscow.
Huntington, Ernest K., elec. engr., operating dept., Rochester Gas & Elec. Corp., Rochester, N. Y.
Irland, George A., asso. prof. of elec. engg., Bucknell Univ., Lewisburg, Pa.
Jones, Edward O., sales engr., Gen. Elec. Co., Buffalo, N. Y.
Langner, Frederick W., asst. to chief engr., Socony-Vacuum Oil Co. Inc., Olean, N. Y.
Macmillan, Campbell, research engr., motor dept., Gen. Elec. Co., Schenectady, N. Y.
Markowitz, Jesse, instructor, school of technology, College of the City of N. Y., New York.
Morrison, George, sales engr. and director, Commonwealth Elec. Corp., Welland, Ont. Canada.
Nimmo, William F., asst. mgr., elec. dept., Virginia Elec. & Pwr. Co., Norfolk, Va.
Oehler, John F., elec. engr., Bethlehem Steel Co., Lackawanna, N. Y.
Oetinger, Herbert W., asst. to vice pres., Duke Pwr. Co., Charlotte, N. C.
Phillips, Frank D., asst. designing engr., Gen. Elec. Co., Schenectady, N. Y.
Plummer, Ernest W., asst. supt. of meters, Buffalo, Niagara & Eastern Pwr. Corp., Buffalo, N. Y.
Reid, Charles R., asst. general supt., Shawinigan Water & Pwr. Co., Montreal, Que., Canada.
Runciman, Arthur S., supt. of transmission lines, Shawinigan Water & Pwr. Co., Montreal, Canada.
Scott, Lee R., elec. engr., Rochester Gas & Elec. Corp., Rochester, N. Y.
Stewart, Douglas C., asst. elec. engr., Buffalo, Niagara & Eastern Pwr. Corp., Buffalo, N. Y.
Van Olinda, Frederick, division engr., Brooklyn Edison Co. Inc., Brooklyn, N. Y.
Vincent, Gilbert I., rate engr., Niagara Hudson Pwr. Corp., Syracuse, N. Y.
Walker, John R., asso. elec. engr., U.S. Bureau of Reclamation, Denver, Colo.
Zielinski, Henry H., resident engr., AEG, German Gen. Elec. Co., Schenectady, N. Y.

33 to Grade of Member

## Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election

of any of these candidates should so inform the national secretary before Dec. 31, 1934, or Feb. 28, 1935, if the applicant resides outside of the United States or Canada.

Aiken, C. B. (Member), Bell Tel. Lab., N. Y. City.
Ainsworth, V. A., Maritime Elec. Co. Ltd., Fredericton, N. B., Can.
Anderson, E. F., Portland Gen. Elec. Co., Portland, Ore.
Audlin, L. J. (Member), Niagara Hudson Pwr. Corp., Syracuse, N. Y.
Bedford, B. D., Gen. Elec. Co., Schenectady, N. Y.
Blake, W. J., Jr., Virginia Pub. Serv. Co., Alexandria.
Broverman, M., Gen. Elec. Co., Pittsfield, Mass.
Brown, L. K. (Member), N. Y. State Elec. & Gas Corp., Lancaster, N. Y.
Carpenter, J. W. (Member), Texas Pwr. & Lt. Co., Dallas.
Clark, G. A. (Member), Consumers Pwr. Co., Jackson, Mich.
Cone, W. S. (Member), 314 Montery Rd., S. Pasadena, Calif.
Crosby, C. L., Allis Chalmers Mfg. Co., Richmond, Va.
David, K. I., Pacific Pwr. & Lt. Co., Portland, Ore.
Davies, L. S., Provincial Mental Hospital, Essondale, B. C., Can.
Dunstan, A. M., Federal Pwr. Comm., Washington, D. C.
Elias, N. M., 333 Sixth Ave., N. Y. City.
Endres, L. M., Natl. Park Service, engg. div., Washington, D. C.
Fansler, B. I., Appalachian Elec. Pwr. Co., Roanoke, Va.
Farace, S. H., Phila. Elec. Co., Philadelphia, Pa.
Fassett, F. C., 100 Seward Ave., Detroit, Mich.
Finsterwalder, C. J., 22 Broadway Terrace, N. Y. City.
Fishwick, A., Illinois Bell Tel. Co., Chicago.
Formhals, W. H., Lehigh Univ., Bethlehem, Pa.
Friddle, C. G., Cleveland Elec. Illum. Co., Cleveland, Ohio.
Frost, H. C., Defiance Spark Plugs Inc., Toledo, O.
Gibson, A. D. (Member), Buffalo Gen. Elec. Co., Buffalo, N. Y.
Hardgrave, T. W., Gibbs & Hill, N. Y. City.
Harris, C. F. (Member), Westinghouse Elec. & Mfg. Co., Rochester, N. Y.
Hathaway, F. B., Okla. Gen. Elec. Co., Oklahoma City.
Hess, H. M., Wayne Univ., Detroit, Mich.
Hogshead, C. C., Appalachian Elec. Pwr. Co., Roanoke, Va.
Hrivnatz, H. G., Houston Lighting & Pwr. Co., Houston, Tex.
Iber, A. K., Arma Engg. Co. Inc., Brooklyn, N. Y.
Johnson, E. A., Southern New England Tel. Co., New Haven, Conn.
Johnston, F. M., Houston Lt. & Pwr. Co., Houston, Texas.
Jones, M. (Member), Hamilton Hydro System, Hamilton, Ont., Can.
Jordan, W., Westchester Lighting Co., Mt. Vernon, N. Y.
Jorgenson, L. M., Kansas State College, Manhattan.
Kaspar, F. P. (Member), Okla. Gas & Elec. Co., Oklahoma City.
Kemp, C. G. R. (Member), c/o E. M. Gilbert Engg. Corp., Reading, Pa.
Kissel, J., Brooklyn Edison Co., Bklyn., N. Y.
Kneisly, H. L., (Member) c/o E. M. Gilbert Engg. Corp., Reading, Pa.
Kryter, R. J., Esterline-Angus Co., Indianapolis, Ind.
Larkin, G. A., La Crosse Rubber Mill Co., La Crosse, Wis.
Lettine, A., 62 Berkley St., Valley Stream, N. Y.
Lind, H. M., Pacific Pwr. & Lt. Co., Portland, Ore.
London, J. B., Gen. Elec. Co., Charlotte, N. C.
Magee, W. G. (Member), Tide Water Pwr. Co., Morehead City, N. C.
May, M., 815 Victoria Bldg., St. Louis, Mo.
Mayer, E. E. (Fellow), 10 East 40th St., N. Y. City.
McGill, C. W., Edison Elec. Illum. Co. of Boston, Mass.
Merwin, J., Southern New England Tel. Co., New Haven, Conn.
Minichan, D. P., Appalachian Elec. Pwr. Co., Roanoke, Va.
Moore, W. B., Potomac Elec. Pwr. Co., Washington, D. C.
Moreland, H. D., Westinghouse X-Ray Co., Portland, Ore.
Murphy, P. J., Dept. of Public Works, Essondale, B. C., Can.
Pedersen, A. M., Hydro Elec. Pwr. Comm., Niagara Falls, Ont., Can.
Potts, J. C., Wright Aero Corp., Paterson, N. J.
Randall, R., Gen. Elec. Co., Oklahoma City, Okla.
Riebe, F. A., 804 S. E., 46th Ave., Portland, Ore.
Ruggles, L. LaF. (Member), Automatic Elec. Co., Chicago, Ill.
Sampson, C. C. (Member), Gulf Oil Corp., Houston, Texas.
Scott, J. A., Westinghouse Elec. & Mfg. Co., Rochester, N. Y.
Silver, J. T., Federal Pwr. Comm., Washington, D. C.
Simonson, M. L., Okla. Gas & Elec. Co., Oklahoma City.
Sinclair, L. B., Reading Co., Philadelphia, Pa.
Staples, E. B., Holtzer Cabot Elec. Co., Roxbury, Mass.
Streicher, W., 445 W. 153rd St., N. Y. City.
Summers, H. J., City Hall, Torrance, Calif.
Tabb, R. P. E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Tedeschi, F., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Webb, J. M., United Management & Engg. Co., Indianapolis, Ind.
Winter, G. J., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Wirz, A., Buffalo Niagara & Eastern Pwr. Corp., Buffalo, N. Y.
Wolferstan, S. H. P. (Member), Canadian Gen. Elec. Co. Ltd., Montreal, Que., Can.

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**Foreign**

de Silva, S. R., Urban District Councils, Moratuwa, Ceylon.
Krishnaswami, S., Madras Govt., Hydro Elec. Dept., Karur, South India.
Robinson, D. M., Callender's Cable & Constr. Co. Ltd., London W. 12, England.
Sublet, F. J. A., Univ. of Melbourne, Victoria, Australia.
Subramanian, A. V., Maharajaha College, Pudukotta, South India.

5 Foreign

## Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Adams, William C., 801 S. Lynn St., Champaign, Ill.
Babloozian, Levon M., 776 N. Cass St., Milwaukee, Wis.
Demeros, Andrew G., P. O. Box 787, East Pittsburgh, Pa.
Fracker, Henry E., Bell Tel. Labs., 463 West St., N. Y. City.
Gould, Albert S., 41 E. 42nd St., N. Y. City.
Hansen, A. Fred, 2065½ W. 30th St., Los Angeles, Calif.
Jordan, Henry, 7408A Christopher Columbus, Montreal, Que., Can.
Losoncy, William A., 14067 Cherrylawn Ave., Detroit, Mich.
Lynn, Harry H., 10 St. Paul Pl., New Rochelle, N. Y.
Macaulay, John H., Elec. Dept., B.B. & C. India Rwy., Dohad, India.
Roisland, Kornelius, 356 W. 34th St., N. Y. City.
Rose, Edwin L., Dept. of Elec. Engg., Mass. Inst. of Tech., Cambridge, Mass.
Simpson, Sidney, Deputy Loco. Supt., Eastern Bengal R. R., Kanchrapara, Bengal, India.
Strong, Ernest A., Radio Station CJRW, Fleming, Sask., Can.
Stuntz, Hans, 106 Peck Ave., Newark, N. J.
Turnquist, F. A., 4 Birch Road, Wellesley, Mass.
Wagoner, K. S., 320 Wisconsin, Oak Park, Ill.

17 Addresses Wanted

# Engineering Literature

## New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

Der ELEKTRISCHE WIDERSTAND des MENSCHLICHEN KÖRPERS gegen TECHNISCHEN GLEICH- und WECHSELSTROM. By H. Freiberger. Berlin, Julius Springer, 1934. 146 p., illus., 10x6 in., paper, 9 rm. This report covers an extensive experimental investigation of the electrical resistance of the human body, carried out under the auspices of the Berlin generating station and various organizations of electricians. Careful measurements were made upon corpses and living beings, under conditions that reproduced those of the usual electrical accidents. In addition, previous work is reviewed, and the practical use of the conclusions is explained.

FIVE PLACE TABLE of NATURAL TRIGONOMETRIC FUNCTIONS to HUNDREDTHS of a DEGREE. Compiled by Amelia De Lella. New York, John Wiley & Sons, 1934. 10x8 in., paper, $1.00. These tables give the sines, cosines, tangents, and cotangents for every hundredth of a degree from 0 to 90. They are printed in facsimile typescript, clearly and legibly, upon a page of convenient size. The values correspond to those given by Briggs.

HEAT. By J. M. Cork. N. Y., John Wiley & Sons, 1933. 279 p., illus., 9x6 in., cloth, $3.00. This text aims to provide the advanced student with a survey of the field which includes recent developments as well as the older classical treatment of the subject. The presentation is brief, but complete, and references to original papers enable the student to investigate particular subjects further.

MECHANICAL VIBRATIONS. By J. P. Den Hartog. N. Y. and Lond., McGraw-Hill Book Co., 1934. 390 p., illus., 9x6 in., cloth, $5.00. This book is intended for use as a college textbook and also aims to meet the needs of practicing engineers. The theory is presented in an understandable form, and its practical applications to water wheels, steam turbines, automobiles, airplanes, Diesel engines, and electrical machinery are discussed in some detail. There is a select bibliography.

MITTEILUNGEN aus den FORSCHUNGSANSTALTEN. Bd. 3, Hefte 3 and 4, July and August, 1934. p. 51–84, 85–110. Berlin, VDI-Verlag, illus., 12x8 in., paper, Heft 3, 3.80 rm.; Heft 4, 2.90 rm. These 2 numbers contain, as their chief contents, the report of an extensive experimental study of the resistance of steel to corrosion fatigue, and of methods of increasing this resistance by adding inhibitors to the corroding liquid. Other articles include one on a new electric railway car, another on the manufacture of an unusually heavy casting, and a third discussing the comparative merits of Strauss and Scherzer lift bridges.

PHYSIKALISCHE EIGENSCHAFTEN und FEINBAU von NATUR- und KUNSTHARZEN. (Kolloidforschung in Einzeldarstellungen, Bd. 11.) By R. Houwink. Leipzig, Akademische Verlagsgesellschaft, 1934. 225 p., illus., 12 rm. The first part of this book gives the results of an extensive investigation carried out by the author of the elastic and plastic properties of the natural and synthetic resins. In the second part the data obtained are made the basis for a theory of the structure of resins, which explains the relation between structure and mechanical properties. Finally, the relation between structure and optical and roentgenographic properties, and viscosity is studied.

TEXTBOOK of APPLIED HYDRAULICS. By H. Addison. N. Y., John Wiley & Sons, 1934. 409 p., illus., 9x6 in., cloth, $5.50. This textbook contains, in part 1, a compact summary of the fundamental principles of hydraulics, and in part 2, a longer but equally condensed description of the practical application of these principles to engineering problems, turbines, pumping machinery, power transmission, etc. The book is of college grade, and especial attention has been given to the needs of readers whose work is not directly connected with hydraulics but who need to be familiar with hydraulic practice.

### Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

# Industrial Notes

**General Cable Appointments.**—George Sherry has been appointed general merchandise manager, and H. B. Tompkins general sales manager of the General Cable Corp. Mr. Tompkins was previously manager of supply sales, General Electric Supply Corp.

**Holophane Co. Appointment.**—A. D. Cameron has been elected vice president of the Holophane Co., Inc., 342 Madison Ave., New York. Mr. Cameron joined the organization in 1931 as manager and his new duties will be in particular relation to sales. His headquarters are in New York.

**Okonite Executive Made President of NEMA.**—Frank C. Jones, president of the Okonite Co., was elected president of the National Electrical Manufacturers Association at its last meeting. Mr. Jones became identified with the Okonite Co. immediately following discharge from military service after the World War, when he entered the factory of the company at Passaic. With his election as treasurer he was transferred to the New York office, subsequently being elected vice president and general manager. In 1932 Mr. Jones assumed the duties of president of the Okonite Co., when H. Durant Cheever, who had occupied that office, became chairman of the board. Mr. Jones has devoted considerable time to the activities of the National Electrical Manufacturers Association, concentrating particularly on its wire and cable work. He is chairman of the code advisory committee of NEMA and chairman of the supervisory agency for the wire and cable subdivision of the electrical manufacturing industry. He was formerly chairman of the wire and cable section and also of the paper cable group of NEMA.

**Allis-Chalmers Introduces New Motor.**—The new "Seal-Clad" squirrel-cage motors introduced by Allis-Chalmers Manufacturing Co., Milwaukee, are of open-type construction, with permanent coil protection. Hard, smooth, Bakelite shields are sealed over the stator coils giving protection against metallic dust, grit, oil, moisture, mild acids and other agents injurious to insulation. They are built in ratings up to 25 hp, 1800 rpm, and suited to a much broader range of application than the ordinary open motor. These motors have cast-steel frames, twistless and distortionless stators, silver-brazed, indestructible rotors, oil and dust-tight sleeve or anti-friction bearings.

**New Contactor Line.**—Ward Leonard Electric Co., Mount Vernon, N. Y., announces a line of a-c and d-c contactors that for several years have been used in their control assemblies and are now available as separate units. They can be used as control contactors for motors, for disconnect purposes in conjunction with suitable auxiliary switches, for electric ovens, various other electric control applications and for special control panels. High contact pressure with low operating and holding currents in the coil are among the features claimed for these contactors. Additional normally open or normally closed auxiliary contacts can be furnished when required.

**New Weatherproof Safety Switches.**—A new line of weatherproof, dust-tight type A safety switches in standard sizes from 30 amperes to 600 amperes capacity has been announced by the Electric Controller & Mfg. Co., 2708 E. 79th St., Cleveland, O. These switches use the same switch mechanism that is furnished with the standard EC&M safety switch which is of type A construction and should not be confused with the type C safety switches using lighter construction and without safety interlocks. Outstanding features of these safety switches are compactness, narrow width, light weight due to steel construction, semi-floating, double break V-blades, V-stationary contacts backed up with steel springs which guarantee full contact under heavy pressure.

**Raytheon Acquires Charging Equipment Line.**—The Raytheon Manufacturing Co., electrical equipment division, Waltham, Mass., announces the acquisition from the Square D Co., Detroit, of the latter's "RectiFilteR" business. RectiFilteRs are devices for changing alternating current to direct current, the conversion being effected with no moving parts. They consist of transformers, rectifying elements, choke coils, and condensers. In some cases meters, relays, switches, and other control equipment is included. RectiFilteRs are designed for operation from any a-c power circuit and by appropriate design of the transformers and rectifying elements can be made to deliver direct current at almost any combination of voltage and current. The Raytheon line includes standardized RectiFilteRs for broadcasting, theater, fire alarm, signal, telephone, and battery charging service. Among the various sizes are low voltage units rated at a few milliamperes to over 20 amperes and others delivering as much as 12,000 volts at 2 amperes.

**Marine Radio Telephone Equipment.**—A new type of radio telephone equipment which enables captains of fishing vessels, harbor craft and yachts to have telephone service at sea comparable with that on land is being shown for the first time at the Marine Exhibit, 80 Broad Street, New York. When within range of a coastal harbor telephone station providing this service, captains are able by means of this equipment to talk to their offices, their homes and in fact to almost any destination as easily as though they were on land. They merely pick up a telephone, located for example in the pilot house, press a button on the instrument and say "Marine Operator." Promptly a voice replies with the familiar "Number Please" and the call goes through as do millions of land calls daily. When the ship itself is called, a selective device rings its bell but not that of any other ship.

The equipment designed by Bell Telephone Laboratories for the Western Electric Co., consists of a telephone and a control unit, a cabinet which contains a 50-watt transmitter, a superheterodyne receiver, and a power unit. Crystal control keeps both transmitter and receiver on frequency at all times, eliminating tuning. One antenna serves for both sending and receiving. A bulletin on the new equipment has been published by the Western Electric Co., 195 Broadway, New York.

# Trade Literature

**Clip-On Ammeter.** Bulletin, 4 pp. Describes the new Ferranti clip-on ammeter with a wide range of full scales and variety of frames, and with openings to take busbars up to $4^1/_2$ by $3^1/_2$ inches. Twenty-three of the more important features of the clip-on ammeter are emphasized. Ferranti Incorporated, 130 West 42nd St., New York.

**Relays.**—Bulletin, 12 pp., "Weston Relays." Describes a comprehensive line of sensitive toggle, polarized, power and time delay relays. Weston Electrical Instrument Corp., Newark, N. J.

**Insulation Testing Equipment.**—Bulletin 934, 12 pp. Describes dielectric strength test sets with potential ranges of 200 to 30,000 volts; insulation resistance meters and other instruments. Sound Engineering Corp., 416 N. Leavitt St., Chicago, Ill.

**Circuit Breakers.**—Catalog 5, 14 pp. Describes a new line of air circuit breakers, type HD (heavy duty). Previous desirable features, such as high speed of opening, simple construction and magnetic blowout action have been retained in the new line. In addition, the use of inverted brushes and secondary and carbon contacts is introduced in air breakers for the first time. The new breakers have exceptionally high interrupting capacities. Roller-Smith Co., 233 Broadway, New York.

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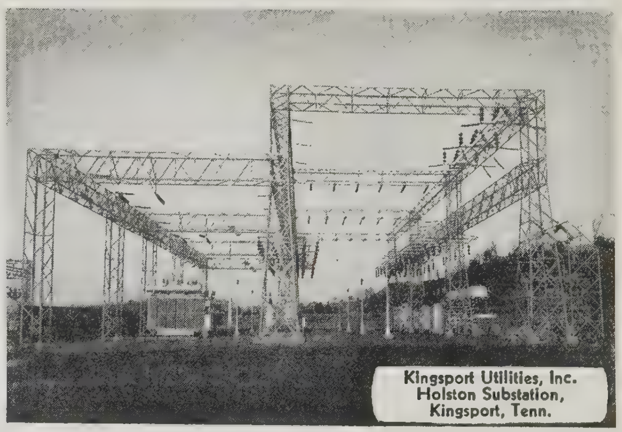


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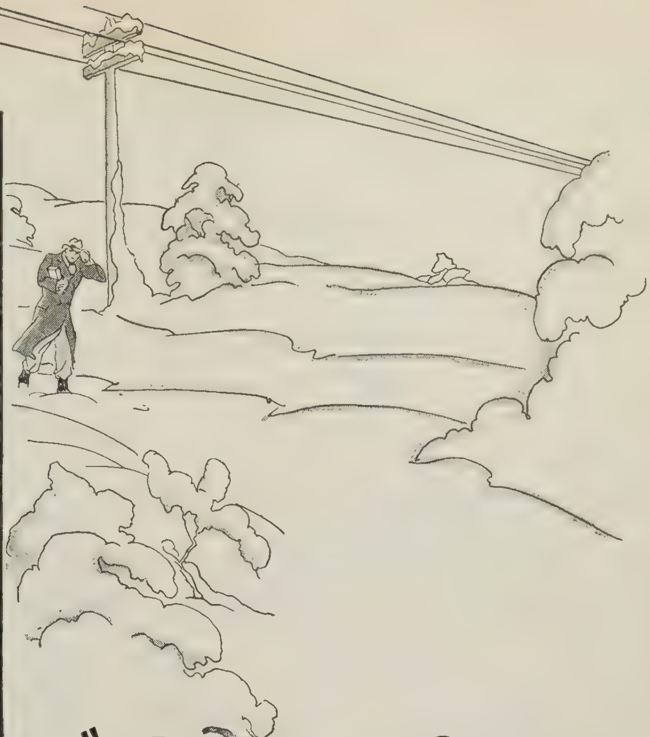

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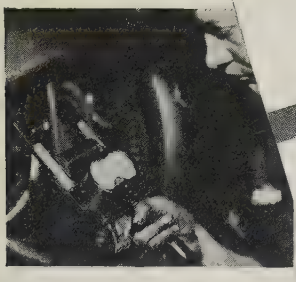

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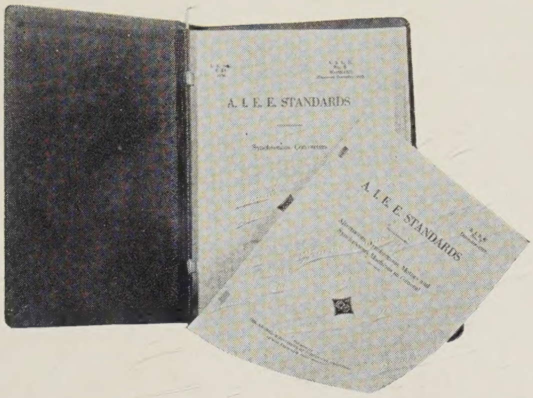

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